Vitrified Paving Brick

A Review of Present Practice in the Manufacture, Testing and Uses of Vitrified Paving Brick.

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PREFACE.

Since the first edition of this booklet was published in 1895, the paving brick industry has developed into one of the large, firmly established industries of this country, while the merits of vitrified brick as a paving material are now so universally known that it has become the most popular of pavements for cities, towns and even counties.

After the industry got a successful foothold in 1885 there was such a rapid development during the following ten years and the demand and prices became so attractive that too many brickmakers rushed into the new and enticing field, for some were inadequately equipped to produce a good paver, or their clay was not suitable to make a durable paver, or, under the stimulus of growing markets and increasing prices they pursued the short-sighted policy of rushing out quantity, immaterial as to quality of the brick. In consequence, many poor brick were put on the market at a time when the public was not educated to distinguish between good, indifferent and bad brick—a paver was still only a paver to most consumers. There was also a woeful lack of harmony among city engineers as to what constituted a good paver, how to lay them and how to test them. The prompt work of the Testing Committee of the National Brickmakers' Association soon removed the latter confusion, while experience more slowly settled the former.

This setback, of which full advantage was taken by the competitors of brick, was not without its salutary effect, and since then the industry has been established on a more conservative, healthy basis. The small, imperfectly equipped plants have been succeeded by fewer but very much larger, well equipped factories that are under able business management, large stocks and usually several grades and sizes are carried, while the inexorable law of the "survival of the fittest" has eliminated those whose clays were not suitable.

The use of paving brick is now mainly a question of freight. The weight of 1,000 pavers is so large, from four to six tons, that a long haul greatly increases their cost. The use of brick is, therefore, largely confined within a moderate radius of where suitable clays occur. Thus, New England, with its great wealth and dense population, has used comparatively little brick on account of the excessive freight, while local macadam is usually good and cheap. The state of Ohio, on the contrary, with its great abundance of suitable clays, has scarcely a town of 500 that has not at least paved its main street with brick.

Vitrified brick is now exclusively employed in many of the larger cities for sewers, for which its exceptional hardness pre-eminently adapts it, while its use is steadily growing among our more advanced architects for the exterior of buildings, for under skillful handling it lends itself readily to picturesque effects which not only do not fade, but remain clean—a feature that is so rare in any other building material in our western cities.

Very recently a careful comparison was made in Indianapolis (see CLAY-WORKER August, 1909) of all the various paving materials to find the one most suitable for a speedway for automobiles. After elaborate tests, in which no expense was spared, it was found that vitrified brick was the best. The decision is too recent to have the great influence that it at least prognosticates for the industry. For, with the very rapid growth in the use of the automobile and its increase in power, the enormous mileage of macadamized roads that this popular machine has developed will largely give way to brick, for the modern automobile is found to rapidly wear and heavily cut into even well maintained macadam roads.

The writer takes this opportunity to express his thanks and appreciation to the many engineers who favored him with local data and their personal experience.

St. Louis, Oct. 11, 1909. H. A. WHEELER.

HISTORY OF PAVING BRICK.

Development Abroad.

Brick for street paving has been in use for more than a century in Holland, where the absence of natural paving material developed a very durable quality of paving brick by mixing the fine river silt or mud with sand. The village of Moor, on the river Yssel, is especially famous for the excellence of its brick and the magnitude of its paving brick industry.

To a much less extent and for a shorter period, they have been used in northern England, especially in Staffordshire and Leeds; under the name of "blue brick" and "terro-metallic ware," where their application is restricted more to stables, chemical works and similar places where a non-absorbent brick is desired. When the clay is not readily fusible, slag, mill cinder, or chalk dust is added in English practice to secure the fluxing or vitrification that is so essential in this class of brick.

Development in the United States.

Paving brick was first used in the United States at Charleston, W. Va., in 1870, a town of 12,000, where a small section was laid as an experiment. This proving satisfactory, a block of one of their principal streets was paved in 1873, in grading for which it was necessary to take up the small section laid in 1870. This is still in use, although laid on a poor foundation of boards, and while the street has been repeatedly torn up for laying pipe, etc., it is still in fair condition after thirty-five years' service. A sample of this brick kindly sent by the city engineer, Mr. W. A. Hogue, shows it to be a side-cut, repressed, hard burned building brick of high density,

or 2.48, and it absorbs 4.5 per cent on soaking twenty-four hours.

Bloomington, Ill., a town of 26,000, laid an inferior paving brick in 1875, on one of their principal streets that lasted twenty years before it was replaced by a high grade shale paver. A sample courteously forwarded by Mr. W. P. Butler, the city engineer, shows that it was made from a very poor glacial clay by the "slop" process (or from a very soft mud) by hand and was not repressed. It shows an absorption of 4.33 per cent after twenty-four hours immersion, it had a density of 2.11, which is very low, and it showed a wear of 1 to 1½ inches.

St. Louis put down three trial lots of brick paving in 1880, one of which was the result of experiments dating back to 1873, the Sattler brick. They all proved failures, from being either too soft or too brittle, although they were laid on a poor foundation. Another lot of the Sattler brick was tried in 1881 that was successful, but the maker was unable to furnish a uniform, reliable brick, as he used a fireclay that was too refractory, besides having other manufacturing difficulties. These failures made such a bad impression on the city authorities, although made in the infancy of the industry and before any first-class pavers had been produced in this country, that no further effort was made to use brick until 1895. Since then brick has not only become very popular, but today is used almost exclusively on the residential and semi-business streets and alleys.

Wheeling, W. Va., put down an impure fireclay paving brick in 1883 that was so successful as to make this one of the important pioneers of the paving brick industry, from the confidence it inspired; some of these brick are still in use, although most of them were renewed after twenty years.

Decatur, Ill., also put down a vitrified brick this same

year that was made from a glacial clay, which is still in use after twenty-six years' service.

Galesburg, Ill., the nestor of the shale brick industry, laid the first shale paver in 1884, on their principal street, where it is still doing excellent service.

Growth.

The year 1885 witnessed the first substantial increase in the use of vitrified brick, as during that year it was laid at Columbus, Zanesville and Steubenville, Ohio, and Peoria, Ill. Since then its use has steadily forged ahead, although at first the progress was slow. As the accumulated experience of brick pavements in actual use grew more favorable and more voluminous it developed confidence in the new material. Finally the ability to secure a strictly first-class, durable, low maintenance pavement at a moderate cost appealed so strongly to cities of the second class and large towns that a regular boom developed by 1895. There were over 175 plants devoted to vitrified brick, some of which had outputs as high as 50,000,000 to 100,000,000 brick annually and with plant investments as large as $500,000 to $1,000,000. The expanding markets and high prices that resulted from the boom enticed many small plants to abandon the building brick trade and enter the paving brick market, especially if shale was available, as at first too many thought that any shale would answer. Many of those plants were inadequately equipped to produce a good grade of vitrified brick, while others used a clay from which it was impossible to make a tough paver. Still others crowded their plants and shipped out as No. 1 pavers anything that was harder than a salmon brick and not warped beyond recognition.

When the boom subsided it had the wholesome result of putting many such plants out of business; others went back to their former legitimate business, while others were ab-

sorbed by the larger plants, where the clay had proven satisfactory.

By 1894 vitrified brick had so favorably impressed the city engineers that in a canvass of the new pavements specified that year in thirty-two leading cities, 44 per cent of the new work was to be vitrified brick, 32 per cent macadam, and 24 per cent asphalt. This was certainly a very flattering lead over its two great rivals, and especially over macadam, its much cheaper competitor.

While the very large cities, with their characteristic conservatism, were slower in adopting brick, most of them have since used it, if within reasonable freight haulage, for the alleys, for the residence streets and for the semi-business streets. A few efforts have been made to lay it on the downtown, heavy traffic streets, where granite or similar tough stone is usually employed, as it is so much less noisy and smoother than stone blocks.* While it has not the durability of the granite, its compensating advantages are regarded by many as sufficient to justify its occasional renewal, especially as the first cost is usually about half.

The railroad engineers have shown the highest confidence in the ability of vitrified brick to successfully resist the heaviest traffic, as it has been most extensively used by them for paving freight yards where the teaming is usually of the heaviest nature. They usually draw specifications, however, that admit only the highest grade of brick or block.

Misconception of the Term.

DEFINITION OF THE TERM VITRIFIED BRICK.

There is frequently a misconception as to the definition

*A noteworthy example of vitrified brick under very heavy traffic is the block on LaSalle street, opposite the court house, in the heart of Chicago, which was laid with Purington brick in 1894, of the standard or small size; after fifteen years' service, this pavement is still in fair condition.

of vitrified brick, as unless a brick shows a decidedly glass-like fracture, some refuse to call it vitrified, and even condemn brick from lack of such glassiness that are not infrequently the toughest and most durable of pavers (brick with a dense stonelike fracture). They quote Webster to substantiate their claims, thereby failing to discriminate between a popular definition and a technical or special use of the term. The No. 1 pavers that are now on the market, whether made from impure fireclay or shale, are always vitrified, although the latter are usually more thoroughly vitrified.

Study of the Changes in a Clay.

To appreciate the correct use of the technical term of vitrified brick, it is desirable to look at the change that occurs in paving clays in passing from the condition of a mud to a glassy mass. A plastic clay or shale, when mixed with a proper amount of water, makes a mud or paste that can be readily molded, and it is tenacious enough to retain the shape given to it in molding, if carefully handled. On drying off the admixed water that rendered it plastic, it shrinks 5 to 11 per cent to a firm, earthy mass that readily bears handling, although it is so soft as to be easily scratched by the finger-nail, and the individual particles of clay can be easily distinguished. On heating the dry clay to a red heat, or about 1,200 degrees F., the chemically combined water is driven off, which renders the clay non-plastic, it again begins to shrink and to grow hard and strong. As the heat is raised above redness, a marked increase occurs in the strength, hardness and shrinkage, but the individual particles of clay are still readily recognized and the mass is quite porous. When the heat is further raised to about a bright cherry heat, or from 1,500 to 1,800 degrees F., depending on the clay, it shrinks an additional 5 to 10 per cent, it is very much stronger, much less porous, has acquired the hardness of tempered steel, the

Point of Incipient Vitrification.

individual particles are no longer recognizable, but the shape is perfectly retained. This point, which is quite well defined, I have called the point of incipient vitrification. From thence, on further heating, to the stage of a molten mass, there is no longer any sharp line of demarkation, as it imperceptibly becomes more and more vitreous, it slowly and gradually begins to soften and if exposed to pressure (from the weight of overlying brick) it more or less changes its shape ("kiln marks"). On still further raising the heat, the clay becomes a very viscous semi-liquid, which, when chilled and broken, presents a glassy to scoriaceous appearance.

Viscous Vitrification

From the point at which the clay particles have sufficiently coalesced that they can be no longer recognized, or the point of incipient vitrification, to the point of viscosity, requires an increase in temperature of 100 to 600 degrees F., depending on the clay, and is usually 400 degrees in the clays suitable for paving brick. Midway between these two points the clay ceases to be porous and stops shrinking; it has attained its maximum hardness and slightly scratches quartz; it has a maximum toughness and cross-breaking strength, if slowly cooled; the fracture shows complete coalescence of the particles, or it is completely vitrified; and the shape is perfectly retained, if not subject to pressure. This stage, while not sharply defined, I have called the point of complete vitrification, and though difficult to describe, it is quickly and easily recognized by the trained eye. It is the stage that clay should be brought to in order to make an ideal paving brick, although the weight of the overlying brick is apt to slightly indent or "kiln mark" the brick. If heated higher, there is a very slight loss in hardness, a much greater risk of brittleness; there is a marked tendency to excessive distortion and the fracture is almost glassy; yet this advanced stage is what some think a brick should be brought to in order to

Complete Vitrification.

be called vitrified from Webster's point of view,* as it absorbs no water.

Salmon brick, having only been exposed to a red heat, are extremely porous, or absorb from 15 to 30 per cent of water; they are very soft, or from 2.5 to 3.0 in hardness; and they are very weak, as they are in the initial stage of shrinking, hardening and strengthening.

Hard building brick, having been raised to a higher or light cherry red heat, are less porous, or absorb from 6 to 15 per cent of water; they are much harder, or from 4.5 to 5.5 in hardness; they are much stronger; and while considerable shrinkage occurs, the distinct grains of the clay are still evident.

Fire clay paving brick usually exhibit a homogeneous, compact, dense body, in which the grains of clay can no longer be discerned, as they have reached the stage of incipient vitrification; they are slightly porous, or absorb from 3 to 6 per cent of moisture; they are very hard, being able to scratch glass or steel, or are 6.0 to 6.5 in hardness; and they are very tough and strong. They are sufficiently dense and strong to successfully withstand frost, and are hard and tough enough to wear well under moderate traffic.

Hard-burned shale pavers usually exhibit a very dense, thoroughly homogeneous, compact body that shows complete vitrification; they are very slightly porous, or absorb from 0.5 to 3 per cent of moisture; they are extremely hard, being

*The superficial glassy faces on brick that have been air checked through faulty kiln firing should not be confused with the true fracture. For, on breaking such a brick, the body will have the dense, stonelike structure that is characteristic of complete vitrification, but which shows no glassiness whatever. The air checked face, however, looks decidedly glassy, but it will be found to be only skin deep, or only where the air has struck the crack in the brick.

about able to scratch quartz; and are very strong and tough. They are pre-eminently adapted for street paving, if slowly cooled.

The salmon and building brick are too soft, too porous and too weak for street paving purposes; the two latter are both suitable for pavers, and are vitrified, but the important distinction should be made that one is only incipiently or slightly vitrified, while the other is completely or thoroughly vitrified.

CLAYS EMPLOYED.

Three classes of clays are employed for the manufacture of paving brick, to-wit

I. Surface clays, as the drift, loess and residual clays.

II. Impure fire and potters' clays.

III. Shales.

Surface Clays.

I. SURFACE CLAYS.—The surface clays are seldom suitable for pavers, although so very extensively employed for building brick. They are usually too siliceous, or contain from 60 to 80 per cent in silica, and occasionally are so very calcarous, or have from 10 to 25 per cent of lime, that it is practically impossible to vitrify a large percentage without losing their shape. For the range in temperature between the points of incipient and viscous vitrification in such clays is so small as to require a perfection in the control of the kiln that renders them commercially impracticable. While the earliest pavers, or those of Charleston, W. Va., and Bloomington, Ill., were made from such clays, they were not vitrified, but only very hard-burned builders, and their endurance was due to the light traffic of a small town rather than to su-

perior quality. In a few cases* surface clays have a composition that is favorable for successfully burning a large percentage into hard, tough brick, but these are the exception, and present experience does not indicate that it will pay to add the mixtures necessary to convert them into a good paving material, as is done in Holland, in competition with the many large bodies of shale that are favorably constituted for making cheap and superior paving brick.

Fire and Potters' Clays.

II. IMPURE FIRE AND POTTERS' CLAYS.—In point of history the impure fire clays* were next used for making paving brick, and for some time were exclusively employed in the important Upper Ohio district; although they are still quite extensively employed, they are being slowly supplanted by shale, which makes a somewhat cheaper and usually more durable paver. A pure fire clay, on account of its infusibility or the inability to vitrify it, is very unsatisfactory for pavers, as the brick are too porous, lack hardness and strength, and are too expensive to burn; but if quite impure, it can be burned to incipient vitrification, when the brick become dense, hard and strong and make a very fair quality of pavers. It

*As at Decatur, Ill., and Huntington, W. Va. The Huntington clay is a very plastic, tough, safe working clay, standing rapid drying and firing, and is very fine grained. It gives the following analysis by Mr. Otto Rissmann:

	Per cent.
Silica	57.04
Alumina	18.26
Sesquioxide of iron	6.38
Lime	2.41
Magnesia	1.98
Ignition loss	10.16
Total	96.23

*Also known as "bastard fire clay" and pipe clay.

possess the great advantage of being almost impossible to overburn, a point that must be carefully watched with shales or surface clays. For this reason the fire clay brick are less porous, or absorb from 2.5 to 7.0 per cent moisture. They usually successfully withstand the frost, in spite of this porosity, notwithstanding the theoretical opinions of some engineers to the contrary. Brick made from fire or potters' clay usually have a light cream or buff color, from the small amount of iron such clays generally contain, and as the latter is apt to be in the condition of disseminated grains of pyrite or limonite, it gives a brown or black speckled appearance to the light ground mass. The fluxing impurities should exceed 5 per cent in a fine grained fire clay, or 7 per cent in a coarse grained clay, to make it fusible enough for paving purposes. The greater the amount of the fluxing impurities the cheaper it can be burned, and the denser, harder and stronger will be the resultant brick, from the more thorough cementation of the clay particles by the fluxing action of these impurities. The fluxing impurities which render a clay fusible, are iron, lime, magnesia and the alkalies (potash and soda); while the finer and the less dense a clay, the more fusible it is, other things being equal.

Shales. III. SHALES.*—The material from which most of the paving brick is now made, and which is usually found in very much larger bodies than either surface clays or fire clays, is the impure, hard, laminated clay that is known as shale by the geologists. Though only recently used for this purpose, and apparently possessing no plasticity as it lays in thick, stratified beds, it is found to readily work up into a plastic mass when ground, and to usually have the very impure com-

*Shale is incorrectly called "soapstone" or "soaprock" by coal miners, from which it radically differs in every respect; it is also frequently but erroneously called slate by engineers, from which it differs but slightly in origin and composition, but slate can not be rendered plastic by grinding.

position that is so desirable for vitrified brick. This very impure nature is the secret of the success of shales for this purpose, if the physical properties are favorable. While there is a large range in the composition of paving brick shales, they usually range between the limits given in the following table, which is compiled from the analyses of twenty-five carefully collected samples of Missouri paving brick shales that were made by the Missouri Geological Survey, and twenty-five brick centers of the United States, collected from various sources:

COMPOSITION OF PAVING BRICK SHALES.

(Deduced from fifty reliable sources.*)

	Minimum Per cent.	Maximum Per cent.	Average Per cent.
Silica (SiO^2)	49.0	75.0	56.0
Alumina (Al^2O^3)	11.0	25.0	22.5
Ignition loss (mainly H^2O)**	3.0	13.0	7.0
Moisture (H^2O)	0.5	3.0	1.5
Total nonfluxing constituents			87.0
Sesquioxide of iron (Fe^2O^3)	2.0	9.0	6.7
Lime (CaO)	0.2	3.5	1.2
Magnesia (MgO)	0.1	3.0	1.4
Alkalies (K^2O, Na^2O)	1.0	5.5	3.7
Total fluxing constituents			13.0
Grand total			100.0

*There are many analyses in the current literature that purport to be of paving brick clays and shales which differ greatly from the above, but the writer has found them to be misapplied analyses of burned bricks, kaolins, fire clays or other material not used for paving brick.

**Ignition loss includes sulphur (S), carbonic acid (CO^2) and combined water (H^2O), though mainly the latter.

While this range in composition is large, the well-known paving brick* are made from shales that agree quite closely with the average analysis given above, especially in the fluxing constituents, so that this will be a valuable guide as a desirable but by no means necessary composition for a good paving brick clay. A specific analysis is herewith given (from Orton) of one of the best-known shales in the country with regard to the high quality of the brick made therefrom, or the Canton, Ohio, shale (Royal Brick Co.):

ANALYSIS OF CANTON (O.) SHALE.

	Per cent.	
Silica	57.10	
Alumina	21.29	Nonfluxing constituents,
Combined water	6.00	85.69 per cent.
Moisture	1.30	
Sesquioxide of iron	7.31	
Lime	0.29	Fluxing constituents,
Magnesia	1.53	13.18 per cent.
Alkalies	4.05	
Total	98.87	

Condition of the Iron.

An important factor in the composition of shales is the condition of the iron, which is always present in quite large quantities in paving brick shales and which chemists almost invariably report in the form of the higher or sesquioxide. In red to brown shales the iron is largely, if not entirely, in the form of the higher or sesquioxide; in the mottled and variegated shales, both oxides are usually present; in the great majority of shales, however, the iron is the lower or

*As Moberly, Kansas City and St. Louis, Mo.; Leavenworth, Kan.; Des Moines, Ia.; Galesburg and Streator, Ill., and Columbus, Zanesville, Akron and Canton, Ohio.

protoxide form, especially when black, blue or green. There is scarcely a shale bank that does not contain "niggerheads" or tough concretions or round boulders of impure siderite or carbonate of iron, and as they range from 1 to 30 inches in diameter, the larger ones have to be pitched out to avoid breaking the dry pan.

The condition of the iron is a very vital matter in the successful burning of shale, and more than one good shale has been condemned from want of knowledge of this fact and the lack of ability to properly control the burning. For there is a marked difference of over 200 degrees F. in the fusibility, according to the condition of the iron, as the protoxide is much more fusible. It is also very desirable that the iron be uniformly diffused through the clay, for if present as crystals, concretions or seams, it gives a mottled or spotted appearance and produces local vitrification, or in spots. If the shale is thoroughly ground, carefully screened and well pugged, the iron usually becomes so well disseminated as to cause no trouble, even though it occurs as big concretions in the bank.

Influence of Lime.

Another matter that is frequently misunderstood, and faulty decisions made in consequence, is the influence of lime on clays in general. If the lime is present in the form of a silicate, as in feldspar, it is a very valuable flux, and the more the better; but if present in the form of carbonate it will not make a strong brick if in large amounts, while the color will be cream to buff, no matter how much iron* may be present, if the lime is uniformly diffused through the clay. If present as concretions, pebbles or veinlets and not finely ground, the quicklime resulting from the burning is liable to swell and cause popping or cracking on exposure to the air or

*Iron is almost invariably the coloring agent in all naturally colored brick.

on becoming water-soaked. The failure to discriminate as to the condition of the lime has resulted in frequent sweeping statements condemning lime under all circumstances.

Fire Clay Mixtures. When shales are too fusible, fire clay is sometimes added to the extent of 10 to 25 per cent, as at Zanesville, O., and Des Moines, Ia., to "stiffen it," or make it stand up better in the kiln, with satisfactory results. The fire clay shows in the fracture as white or gray spots and if used too freely, it lowers the hardness and toughness of the brick.

PHYSICAL PROPERTIES OF CLAYS.

Limited Value of Chemical Analysis. The chemical discussion of clays has been hastily passed over, on which a volume could be written as, no matter how carefully a clay may be sampled and analyzed, the merits of a clay can never be decided upon from only a chemical analysis. It is of considerable assistance in forming an idea about a clay and within certain limits, will enable one to condemn but never to indorse a clay. To pass judgment on a clay for any purpose, a thorough physical examination is necessary, which gives the information how to work the clay, the kind of the ware that can be made therefrom, and data from which the proximate cost thereof can be estimated. Such a series of physical tests comprise the determination of the following:

PHYSICAL FACTORS OF CLAYS.

1. Plasticity.
2. Water required to make a plastic paste.
3. Shrinkage in drying.
4. Shrinkage in burning.
5. Speed in drying.
6. Speed in burning.
7. Temperature of incipient vitrification.
8. Temperature of complete vitrification.
9. Temperature of viscous vitrification.

10. Density before and after burning.
11. Colors of the burned ware.
12. Strength of the burned ware.

All of these factors have an important bearing on either the manufacture or use of the ware, yet barring the fusibility and color, and then only imperfectly, a chemical analysis gives little or no information on these highly important matters.

Plasticity.

The plasticity is pre-eminently the first question in any clay, as on this properly depends the ability to mold the ware. If too lean to be readily or safely molded, it requires admixture with a "fat" or plastic, or "bond" clay, while if too "fat" or plastic, it needs reducing with sand, "grog," or a lean clay. The plasticity is of special importance in paving brick, as if too plastic, the laminations, which have a weakening effect on the brick, are excessively developed.

WATER REQUIRED.—The water required to render a clay plastic varies considerably, as the finer the grain of the clay, the greater is the quantity required. As paving brick are usually made by the stiff mud process, from 14 to 18 per cent is necessary to secure a tough, plastic magma that can be worked without excessive power yet will give a dense, close body that will have a moderate air shrinkage. If too much water is used, the clay can be worked with much less power, but the laminations and shrinkage are excessive and it is difficult to handle and hack the brick without indenting them. From 18 to 25 per cent is used in soft mud brick and from 5 to 10 per cent in semi-dry pressed brick, while dry pressed brick only have the 2½ to 4 per cent that all air-dried clays possess and are entirely free from drying shrinkage.

Shrinkage.

SHRINKAGE.—The shrinkage is a very important matter to the manufacturer and must be carefully determined in order to know how much larger the dies or molds must be

made to produce a given sized brick. It is made up of two factors, or the air shrinkage and the fire shrinkage.

AIR SHRINKAGE.—The air shrinkage is the reduction in volume that takes place in drying a plastic clay mass. The air shrinkage will be the greater as the plasticity increases, as the percentage of water increases and the finer the grain of the clay. Thus the shrinkage is much greater in soft mud process than when the same clay is worked by the stiff mud process and becomes almost nil in the semi-dry process and is entirely absent in the dry process. Coarse and lean sandy clays also experience but a moderate shrinkage in drying. According to the amount of water used and the grain of the clay, the air shrinkage usually varies from 4 to 8 per cent.

If the shrinkage is excessive or uniformity of size is important, as in terra cotta, grog or sand is used to reduce the shrinkage.

FIRE SHRINKAGE.—The contraction that takes place when raised above a red heat, or the fire shrinkage, varies considerably, being greater in fine than coarse grained clays. If the lime and magnesia are high, the fire shrinkage will be slight and even absent in a high lime clay. Usually it ranges from 5 to 10 per cent, which amounts to 10 to 20 inches of "settle" in a kiln, according to the clay and heighth of setting. The burning off of a kiln is usually determined by the "settle," although it is not always reliable or regular.

Drying

The speed of drying determines the care with which a clay must be dried, and the size and capacity of the drying chambers. Some lean clays can be dried in twenty hours without checking (small cracks), while some strong clays require three to five times as much time in order to dry without cracking. This is a very important factor to know in designing a plant and often causes heartrending outlays after a plant is finished from having been overlooked. Too rapid drying is apt to affect the strength, especially with strong or very fine grained clays.

Burning.

The speed in burning is a property that enables some clays to be rapidly heated without cracking, while others have to be slowly fired; this will greatly influence the method of firing the kiln and also determine the number of kilns required to furnish a given output.

The temperatures of incipient, complete and viscous vitrification are very important in all clays, as it is necessary to attain the first to develop strength, while with pavers it is not only of vital importance to readily attain the second, but there must be a wide margin each side of the point of complete vitrification to enable the kiln burner to produce a large percentage of No. 1 brick. For if this margin is small, there will be a heavy loss from either overburned and misshapen brick, or from soft, underburned brick.

Density.

The density of the burned ware varies considerably, as some clays give a porous, light body, while others give a close, dense, uniform, stone-like body, which latter is absolutely necessary in paving brick.

Color.

The color of the burned clay is a vital matter with most clay ware, and is of great assistance in paving brick in controlling the burning, after once being familiar with the colors of a given clay at different heats.

Strength.

The strength of the burned ware is the crucial test of a paving brick, as on this depends its durability. Many clays that are satisfactory up to this point fail from the severe demands required of a durable paver. In fact, the majority of shales and impure fire clays can not be used for pavers, because lacking the great toughness that is required in a high grade paving brick.

MANUFACTURE OF PAVING BRICK.

Surface Clays.

WINNING THE CLAY.—As the surface clays are now rarely used for paving brick, the usual methods of handling

such clays are seldom used, or the pick and shovel, plow and scraper or cart, disc cutter and automatic clay gatherer, according to the size of the yard and haul. Nor are paving brick clays weathered, a process which increases the plasticity and homogenity, though at the expense of extra handling, loss of time and the locking up of considerable capital; for while this process improves all clays, competition has now forced this beneficial measure to be regarded as a luxury.

Fire Clays. The impure fire clays are usually mined by the room and pillar system, like coal, with which they are usually associated and much resemble in their mode of occurrence and method of handling. Like coal, they are also preferably worked by driving and drawing, or running entries out to the boundary, and then drawing the pillars back to the shaft or slope.

Shales. The shales are usually worked in open pits, after stripping off any surface clays, and are either worked by blasting, or else handled from the solid bank into the car by a steam shovel.

Steam Shovels. If the plant is large enough to keep a steam shovel moderately busy, it is the cheapest and much the best way of working. For a much better mixture of the different stratas is obtained, which differ more or less in every shale bank, since the nose of the shovel rips off fragments from the bottom to the top of the face every time it is loaded. As the face is kept vertical, there is much less delay and trouble in rainy weather by the shale not getting very wet. As the depth of a steam shovel cut is limited to about twenty feet, it is necessary to operate the shovel on a series of benches or terraces, where the shale exceeds 25 to 30 feet in thickness.

There is no limit to the heighth of the quarry face when

blasting is employed, and faces eighty feet high are worked at Galesburg, Ill., and Des Moines, Ia. By putting a one to one-and-a-half-yard shovel on a two-and-a-half-yard machine, steam shovels are able to successfully rip up very hard, tough shales, as at Alton and Galesburg, Ill., and Des Moines, Ia., though not without break-downs that are still too frequent, and further improvements are needed in strengthening the weak points of these valuable machines. By loosening the bank with dynamite, the work can be made easier and much less severe on the steam shovel, but much of its economy is lost when nitroglycerine supplies the energy instead of coal; and if the points of the shovel are kept sharp, they have proved their ability to tear up very tough shales without the assistance of powder. If a yard is making less than 50,000 brick a day, there is usually no economy in a steam shovel, as the shovel crew is idle about 70 per cent of the time, and a daily output of about 200,000 is necessary to keep the shovel constantly at work.

Cars. From the bank or pit to the factory, the clay or shale is usually hauled in either side-dumping or drop-bottom cars, by horse, locomotive or wire rope, and ingenious devices have been introduced for coupling, dumping and latching automatically. Occasionally long belt conveyors are used to transfer the clay from the pit to the crushing floor, but this is usually confined to small plants. For large plants exhaust the clay at the rate of one-half to three acres per year, depending on the thickness of the deposit, as two cubic yards or more are needed per 1,000 brick.

CRUSHING.—Shale is nearly always crushed in dry pans or Chilian mills, with solid mullers or rolls that are usually four feet diameter and twelve inches wide, and which run within a revolving pan nine feet in diameter, with a grated bottom. A pair of such pans can usually supply the largest

size brick machine, and they have proved very satisfactory, as they crush from five to ten cubic yards of average shale per pan per hour. Rolls and centrifugal disintegrators are occasionally used, but they are not satisfactory on most shales, which are usually too tough to be cheaply crushed fine by this system, although very efficient on surface clays.

SCREENING.—From the dry pan the crushed shale should go to screens, and fixed, shaking riddles, and revolving trommels are employed. They all require the use of knockers, to prevent sticking of the wet clay, and at many plants a boy is also needed to keep the screens from clogging. The trommels and shaking screens are more compact than the fixed riddle, but the latter is simpler to clean and repair. In some of the older plants the only sizing accomplished is by the gratings of the dry pans, which is regarded as sufficient and no screens are employed; this is a serious mistake, as it reduces the capacity of the pan and results in very imperfect screening, from the wear and breakage of the bridges of the gratings. As the finer the clay is crushed the stronger the resulting brick, these coarse particles produce an inferior, unhomogeneous product. In fact, most plants are still faulty in not screening fine enough, as four to eight-mesh screens are employed, whereas ten to sixteen meshes per linear inch should be used to give the best results.

PUGGING.—The crushed and screened clay or shale is next mixed and worked with water into a plastic mass by the pug mill, which is a long trough containing a series of wide blades set with a coarse pitch on a heavy shaft. This pugging or tempering should be thoroughly done to remove air inclosures, secure a homogeneous mixture, and reduce the laminations in molding to a minimum; but most pug mills are too short to properly accomplish this, or only six to nine feet long (along the blades), or are pitched too rapidly and are the

cause of many defects in the brick. They should be at least ten to twelve feet long, and have the blades or knives 90 degrees apart. Fire clays are often pugged or tempered in "wet pans" or "chasers," which are small Chilian mills with a solid bottom, while the mullers have a narrow tread. The clay is both crushed and tempered into a homogeneous paste in this pan, being kept in it until thoroughly ground and uniformly tempered. The wet pan yields a superior product to the pug mill, as it can be retained indefinitely in the pan, or until thoroughly tempered; but as it requires a larger plant and takes more labor and power, it is not usually used for paving brick, though in quite universal use for fire brick, sewer pipe, terra cotta, etc.

MOLDING.—Paving brick are usually made by the stiff mud process, although a few small yards still retain the old-fashioned soft mud and repressing system. The mud process has thus far proved the only successful method for securing a large percentage of good pavers, as the intimate bonding of the particles that it insures adds greatly to the strength.

Failure of Dry Press Process.

Numerous attempts have been made to use the semi-dry and the dry press methods, which are so successfully used for building brick, and thereby eliminate the wet shrinkage, with its losses, and the large, costly drying plants, but they have failed to produce more than a small percentage of good pavers. For in the dry or semi-dry press systems, there is no real bonding or cementing between the clay particles, and they merely cohere as the result of the quickly-applied pressure; and unless such brick are burned to complete vitrification, they fail to give a solid, strong, non-porous brick.

Strength of Dry Mud.

To show the strength of the natural bond of the clay particles when worked by the mud process, it was found in testing about two hundred samples of Missouri clays and shales, that the dry mud (before burning) had a tensile strength of

50 to 300 pounds to the square inch, averaging about 150, and the gumbo clays ranged from 300 to 400 pounds, or were much stronger than the natural cements.

Stiff Mud Machines.

The type of machine used for the stiff mud process is usually a continuous-working auger that forces the tempered clay or mud through a forming die; this gives a continuous bar of stiff clay, which passes under an automatic cutter that cuts it into the desired size. As the bar leaves the die, it is usually sanded to prevent the bricks from sticking together in the kiln. Instead of an auger producing a continuous stream of clay, reciprocating plungers are sometimes employed, which give an intermittent bar, and occasionally steam cylinders with clay plungers are used, similar to sewer pipe presses. The first method is the simplest, and this style of machine has been developed to a producing capacity of 12,000 bricks an hour, or about 100,000 per day. Formerly the dies were made about 4½x2½ inches in size, producing an end-cut brick, but of late 9x4½-inch dies are being used, which gives a side-cut brick, and active discussion is constantly going on as to the relative merits of the resulting brick. The side-cut brick is the more shapely and decidedly preferable for building brick and for repressing, but as to which will make the more solid paving brick—the brick with fewer laminations—will have to be settled for each individual clay,* as the writer has seen cases where each has been decidedly preferable to the other.** The weak point of the stiff mud process is the

*To one not experienced in working clays, it may seem odd why a machine that is a success with one clay is a failure with others; but no two clays are alike and the individuality is often so marked as to require wide ranges in the methods of working different clays.

**Tests made on several Ohio clays by Prof. Orton seem to show that the side-cut are better than the end-cut, but the data does not admit of reliable comparison. ("The Clay-Worker," July, 1895).

laminations that must inevitably result from pushing a stream of clay through a fixed die. For the friction of the sides of the die will cause differential speeds in the stream of clay, and these variations must necessarily result in laminations, or lines of demarkation between the different speeds in the clay bar. If the air has been expelled from the clay by the pug mill, these lines can be largely closed up again by a properly shaped die, and a first-class brick will result in which the laminations will be inconspicuous and of no importance. But if the air has not been expelled, or the former and die are not properly designed, there will be an excessive number of concentric lines that divide a cross-section of the brick into a series of distinct and separate shells or concentric cylinders that greatly weaken the brick for withstanding blows or frost. The condition and character of the clay also greatly influence the laminations, as the softer it is tempered or the more plastic it is, the more serious is this trouble. Hence the clay should be worked as stiff as possible to not only make it dense and reduce the shrinkage, but also to reduce the laminations. A very stiff clay needs more power to work it, however, and if too stiff, is apt to break down the machine.

End Cut vs. Side Cut.

Repressing.

REPRESSING.—In most factories the freshly cut brick is immediately repressed in special vertical acting machines known as represses, in which it is momentarily subjected to a heavy pressure, usually on the flat side. This fills out the angles and edges, making a much more shapely as well as a uniform brick, and in some cases it probably decreases the laminations. There is no doubt as to the superior merits of a repressed brick as regards appearance and uniformity in size, but brickmakers are not satisfied as to the internal structure being benefited by breaking the old bond formed under such heavy pressure in the die of the auger machine by the

very differently applied vertical pressure of the repress. Nor are the comparative tests altogether satisfactory that have thus far been made between repressed and unrepressed brick made from the same clay, which seem to indicate a somewhat smaller abrasion loss in the rattler of the repressed brick, as this is largely, if not entirely, due to the heavy rounding of the corners in repressed brick, as against the square or slightly rounded corners of the unrepressed. For the tendency is to round the edges and corners more and more, which gives a better footing to the horse and makes the brick more durable, and brick are now rounded with a three-eighths-inch radius, where formerly only two-eighths to one-eighth was used.

Drying.

DRYING.—The stiff mud brick are hacked or piled direct from the auger machine or the repress in open checker work on cars as high as they will bear their own weight, or six to eight courses high, and dried in long tunnels or drying chambers that are heated either by direct fires or by steam pipes, or by hot air, or by the waste heat from the cooling kilns. On account of the marked difference in the drying properties of clays, the selection and design of a dryer is a very important matter and the dryer must be adapted for the specific clay. Some clays can be rapidly dried in eighteen to thirty hours without checking or injury, while others need forty-eight to sixty hours or longer to avoid cracking to pieces. This means a great difference in the size, arrangement and expense of operating the drying plant, which too frequently is neither appreciated by the brickmaker nor the enthusiastic venders of patented dryers, which generally results in insufficient drying capacity and a goodly percentage of unsound brick.

Burning.

BURNING.—The burning is the most critical part of the paving brick business and is the department that is largely

responsible for the bad brick streets and is often the cause of the balance being on the wrong side of the ledger at the close of the year. This is the more lamentable as it is entirely in the control of the competent brickmaker if he has sufficient kilns, will personally supervise this final department, and has the business sense to prevent underburned, brittle and checked brick from being sent out as No. 1 pavers. While first-class kiln burners, on whom largely depends the success in burning, are none too plentiful, the fruit of their work is easily gauged by the watchful superintendent who, by conscientiously classifying into four grades, should secure the delivery of 60 to 80 per cent of strictly first-class pavers. A serious fault with most paving brick plants in this country is an insufficiency of kilns, as they are the most expensive portion of the plant. Yards that are otherwise equipped with very complete outfits, including the best and latest types of machinery, are frequently deficient in kilns, on which pre-eminently depends the quality of the brick and the success of the yard.

Down-Draft Kilns.

The kind of kiln employed for burning paving brick is the down-draft, whether round or oblong,* as the up-draft type produces too heavy a percentage of soft and overburned brick. A few brickmakers, who tenaciously cling to the ideas they learned when making building brick, try to burn pavers in open top kilns; they succeed in making a few No. 1 or strictly hard pavers, and many No. 2 or soft pavers, and then try to find a customer who can not distinguish the inferior article.

*The round kiln, with a capacity of 40,000 to 80,000 brick, is a great favorite in Ohio, the leading state in the clay industry, but the newer, less conservative western plants have mainly adopted the more convenient, large, rectangular kilns, which hold from 100,000 to 300,000 brick.

Continuous Kilns. The continuous kiln has also been tried on pavers, but it has a discouraging field on account of the heavy shrinkage that complicates the maintenance of the feeding ports. Improvements made at Streator, Ill., Catskill, N. Y., and Erie, Pa., on this type of kiln indicate that its well-known economy in fuel may yet be utilized for burning paving brick, with a reasonable yield of No. 1 brick.

In burning the brick, which takes from seven to ten days, they are finally brought up to cherry or bright cherry heat, or from 1,500 to 2,000 degrees F., which is sufficient to vitrify most shales; but the impure fire clays require a higher temperature, or from 1,800 to 2,300 degrees F.* If shale brick are heated too high, they soften and "wilt down," or melt into a more or less solid mass; yet it is usually necessary to bring them up to a heat which would cause them to stick together if not prevented by sand that is freely sprinkled between them in setting. At this vital temperature, when they border on the condition of a very viscous fluid, the lower brick become "kiln marked" or indented from the weight of the upper brick forcing the lower brick slightly into one another, and care is required to not allow this pressure to become too

*The writer is well aware that many clayworkers estimate their temperatures much higher than given above, but many careful determinations with a reliable pyrometer (Le Chatelier's) have shown that paving brick clays almost invariably vitrify within the above ranges of temperature. The clayworkers have been frequently misled by the very inaccurate determinations of the early, crude and erroneous pyrometers. The use of Orton's or other good makes of pyrometric or seger cones has placed a very cheap, simple, reliable means of estimating and controlling kiln temperatures within the reach of every one, and no plant should attempt to burn a kiln without the use of cones. They cost $1.00 per 100 and the cones cover all the ranges in temperature found on any clay plant, according to the number of the the cone.

great by not setting them too high. Hence paving brick are set only twenty-two to thirty-four courses high, according to the fusibility of the clay, whereas building brick are set thirty-five to forty-five courses high. Coal is used throughout in burning pavers, which do not need the preliminary or water-smoking stage to be done with wood or coke, as in burning building brick. Oil and natural gas have been used in a few places that are so fortunate as to have these superior fuels; they are greatly superior to coal in reducing the labor in burning and in producing a superior quality of brick from the uniformity of the fire, while the air checks that result from chilling, when cleaning the grate bars in coal firing, can be entirely prevented.

Annealing.

After the kiln has been maintained long enough at a vitrifying temperature to heat the bricks through to the center, the kiln is (or should be) tightly closed,* and allowed to cool very slowly. Slow cooling is the secret of toughness and the slower the cooling the tougher the brick. This annealing stage is grossly curtailed at most plants from insufficient kiln capacity, and the kiln is therefore hurriedly cooled down in three to five days, in order to hurry out the brick, even to removing bricks that are so hot as to set fire to the trucks. At least seven to ten days should be allowed for cooling to secure a tough brick, and those who desire the best article

*Prof. Orton, Jr., has lately advised opening the fire doors and chimney flues while the brick are very hot, to hasten the cooling until the top brick reach a dark red, before closing up tight. This is a safe thing to do in the hands of an intelligent burner, as no harm will result if the air is raised to nearly the same temperature as the brick by entering the hot fire boxes and bags; but unless carefully watched, this is a dangerous risk to take. ("The Clay-Worker," April, 1895).

obtainable can well afford to pay the extra cost of still slower cooling, if quality is the first consideration.

Sorting. If the kiln is properly burned, it will be found to have from one to four courses of top brick that are burned extremely hard, but which are more or less air checked by being struck by the cold air in coaling or cleaning the fires. The top course is also more or less freely covered with an adhering film of ashes and dust that have been carried over from the fire by the draft. Such bricks make excellent sewer or foundation brick, as they have a maximum hardness, crushing strength, a minimum porosity and are true and straight.

Beneath this top layer of checked brick to within two to twelve courses of the bottom are No. 1 pavers, or brick that should be perfectly sound, completely vitrified, and have a maximum hardness and toughness. Beneath the No. 1 pavers are two to ten courses of brick which have not received sufficient heat to completely vitrify them, that are classed as No. 2 pavers and which are used for the foundation or the flat course in paving and for building. Beneath the No. 2 pavers are from one to six courses of brick which have not received heat enough to enable them to withstand the frost; they are called "builders," as they are about equivalent in strength, hardness and porosity to building brick, with which they successfully compete.

Field of No. 1 Pavers. With a fire clay, it is possible to produce 90 per cent of No. 1 pavers, as there is no risk from overfiring, though 80 per cent is a high average. With shale, one frequently sees claims by kiln venders of the ability to produce 90 per cent of No. 1 pavers, but such a very high percentage is rarely, if ever, attained, if carefully graded; 80 per cent is a high yield and above the average, as most yards are well satisfied if 70 per cent are strictly first-class or No. 1 pavers.

PHYSICAL QUALITIES OF PAVING BRICK.

COLOR.—The color of paving brick is no criterion for comparing brick made from different clays, as clays vary so greatly in kind and degree of color. Usually the impure fire clays give different shades of buff, while the shales give reds and browns. For a given clay, however, the color is a reliable guide as to heat it has received, if it is burned under the same conditions. The higher the heat, the darker the brick will be, but if the mode of firing the kiln is changed, as from oxidizing to a reducing action, the clay will be made dark in consequence of this reducing action on the iron, and not by the heat. A change in the fuel, as from oil or gas to coal, will usually result in a change in the color at the usual heat for this same reason. Uniformity of color on breaking the brick is a valuable guide in checking the work of the burner, as a black center in a red brick shows faulty firing, while a light colored center shows insufficient time in holding the heat. The outside color of the brick is often compromised and even made valueless as a guide by the sand that is employed to prevent sticking in the kiln, or by fire flashing when using coal that is high in sulphur. Some of the Ohio valley manufacturers salt glaze their brick, which gives a dark gloss to the outside that is very attractive to the superficial observer, but it defeats using the color test unless the brick is broken. Salt glazing has been the cause of many soft brick escaping the inspector's eye, and poor pavements have resulted in consequence, but the practice is fortunately becoming obsolete. For the glazing is only skin deep and soon wears off With some clays, however, salt glazing assures a heat that should vitrify the body, as "the salt will take," or the glaze only occur at a certain minimum heat that assures vitrification with some clays.

Uniformity.

Salt Glazing.

STRUCTURE.—The structure of the brick, as regards its

homogeneity, density and vitrification, are determined by the fracture on breaking the brick, as it is impossible to determine these vital questions from an exterior inspection. The vitrification should be complete and to the center of the brick; it should be free from large spots of unfused matter, which latter indicate sand* or fire clay;* there should be no glassy or spongy spots, which show imperfect crushing and mixing of a more fusible mineral in the clay. The structure should be uniform, devoid of air checks, and free from shakes or marked laminations, especially if accompanied by air pockets. The edges should be free from "ragging," or serrations arising from obstructions in the die. "Kiln marks" or indentations made by the overlying brick in burning should not be excessive, and they usually assure a proper vitrification. The shape should be reasonably perfect and free from marked warping or distortion. Slight variations in the size of the brick may be due to the wear of the die, or to variations in the shrinkage if the clay is not uniform, or to irregular burning, or to irregularities in the cutting table if in length. The latter is of no importance and if the former are moderate, they are of no consequence unless due to underburning, which is quickly discovered on breaking. If these variations do not interfere with the close laying of the brick, and the quality is otherwise satisfactory, they can be overlooked; but snug, close laying is essential to insure the durability of a pavement and any warping or variation that prevents this should cause the rejection of the brick.

Homogeneity.

Variations in Sizes.

HARDNESS.—The hardness of a paver is the property that enables it to successfully withstand the wear of the

*The sand spots are usually due to mixing with surface clays the shale from imperfect stripping, while fire clay seams sometimes occur in the shales.

wagon tire, especially when the brake is applied, and the slipping of the horses' hoofs. Next to toughness or freedom from chipping, it is the most important requisite of a good paving brick. Though its great importance is recognized by engineers and the inspector is ever alert for soft brick, yet an actual determination is rarely made and then by the very imperfect grinding test, which latter is mainly a question of toughness rather than hardness or interpenetration. An indirect estimate of it is obtained by the absorption test, as a well vitrified brick is bound to be very hard, and hence a very low absorption standard will insure hard brick. But it is too important a matter to be arrived at indirectly, especially as excellent brick are found with 3 to 5 per cent absorptions. The writer, therefore, suggests the use of Moh's scale of hardness as a simple, quick, inexpensive way of arriving at the hardness, in which No. 6 is orthoclase feldspar and No. 7 is quartz. Good No. 1 shale pavers are usually 6½ in hardness and are just able to scratch tempered steel.

Testing.

POROSITY.—The porosity of a paver is an excellent index of the degree of vitrification, as if sound and perfectly vitrified, it is almost non-porous. The porosity is measured by the amount of water the dry brick will absorb when soaked in water for a given time, usually 24 hours. The porosity is misapplied by many engineers as a critical index of the ability of paving brick to withstand the action of frost and amusing arbitrary lines are drawn, frequently at 2 per cent, as to the maximum porosity that is permissible, often requiring less than many well-known building stones. This idea would be well founded if non-vitrified brick were used, which are not only very porous, but are sometimes so lacking in strength as to be unable to withstand the disintegrating action of frost. As all paving brick are porous to some extent, it is a question whether the disrupting action of the

Misapplied as a Frost Test.

freezing water exceeds the strength of the brick; if the resistance of the brick exceeds the rupturing action of the crystallizing water, the latter will do the yielding when it freezes, and it is immaterial how porous it is. Now vitrified brick, whether only incipiently vitrified as in the impure fire clays, or completely as in the shales, has a strength that greatly exceeds the disrupting action of frost, as shown by long experience and numerous tests; hence, if the brick is vitrified and has the strength that usually accompanies vitrification, there is no fear of frost disintegration, and this test should be used for its more restricted but still high value as an expression of the degree of vitrification. While the generally accepted rule that the less the absorption the better the brick is true up to a limit of 0.5 to 1.5 per cent, a brick should not be condemned which gives satisfactory tests in the rattler, as is now done by some engineers, because it absorbs more than 2 per cent of moisture. Most of the impure fire clay pavers rarely absorb as little as 2.5 per cent, and often over 5 per cent, yet they have been in successful use for over twenty-five years without being affected by frost. The oldest paving brick in this country, at Charleston, W. Va., which are still in fair condition after thirty-five years' service, absorb 4.5 per cent of water in twenty-four hours, and are only hard-burned building brick made from a surface clay. The Bloomington, Ill., brick that wore out after twenty years' service on their principal street absorbed 4.33 per cent, yet they showed no traces of frost disintegration, and they were a rough, hand-made, soft mud, building brick made from a poor, calcareous, glacial clay. The Sattler brick, a hand-made, fire clay block, absorbed 5.5 per cent, yet they successfully withstood the heaviest traffic of St. Louis, at the entrance of the Missouri Pacific Railroad freight yard, for

Usual Absorption.

many years without showing the faintest trace of frost disintegration.

The No. 1 shale pavers usually show less than 2 per cent absorption and occasionally less than 1 per cent; yet some of these almost non-absorbent shale brick are inferior in toughness and durability to the more porous fire clay pavers. An absorption of less than 0.5 per cent is apt to indicate brittleness, unless unusual care is taken in the annealing, and the best shale pavers generally range from 0.75 to 2 per cent on twenty-four hours' soaking.

Density of Clays.

DENSITY.—Density is a desirable factor in paving brick, as, other things being equal, the denser the better, from the greater quantity of wearing material in a given space. The density is obtained by taking the specific gravity, or else the weight of a given sized brick, or else the weight per 1,000. As different makers vary in the size of their brick, it is dangerous to arrive at the relative densities by comparing the weights of different brick per thousand, unless they are known to be of the same size. Usually standard size unrepressed brick weigh about 6,000 and repressed about 7,000 pounds per thousand. The specific gravity of a brick usually approximates that of the clay from which it is made, as the reduction in size from shrinkage is about offset by the loss in combined water. The shales range from 2.15 to 2.55 and average about 2.38 in specific gravity. The Coal Measure fire clays, whether pure or impure, range from 2.20 to 2.55 and average about 2.40; the Mesozoic, or more recent fire and potters' clays, are lighter and range from 1.90 to 2.22 in specific gravity. Shale pavers range from 2.05 to 2.55, and generally come within the limits of 2.20 to 2.40. Fire clay pavers, not having had the fire shrinkage completed, are usually lighter or range from 1.95 to 2.30, and generally vary from 2.10 to 2.25.

While a given clay will vary in density according to the amount of burning and the consequent shrinkage, the porosity, in consequence of not completing the shrinkage, must not be confused with the specific gravity. The latter is primarily the individual weight of the molecules and if two clays have been equally burned, the density will be the relative weights of their molecules. If, however, the density has been unequally modified by difference in burning, then the porosity, as measured by the absorption, will have to be considered in arriving at an accurate idea of the density, though this can be ignored in vitrified brick as being too small for practical consideration.

Slight Value as a Guide.

CRUSHING STRENGTH.—This property is interesting as a matter of general information, especially as it shows that well vitrified brick are capable of sustaining the greatest pressure known, outside of the metals.* As à factor in the use of brick for paving, it is not of much importance, as the poorest specimens greatly exceed the heaviest load that ever comes upon them and vitrified brick never fail by crushing. Further, the brick that show the greatest resistance to crushing are the overburned brick, which are too brittle to wear well. It is a test that was formerly frequently demanded by engineers, but its slight value and the expense of making the test, if properly done, has resulted in their quite generally abandoning it. Paving brick vary greatly in crushing resistance, though the wide differences that one sees in print are more usually due to the difference in the mode of

*Tests at St. Louis, Cincinnati, Boston, Washington, Buda-Pesth, Berlin and other places have repeatedly shown the crushing strength of vitrified brick to be greater than granite.

Range of Strength.

testing, or else to the selection of the samples.* Reliable samples show ranges as great as 4,000 to 30,000 pounds to the square inch and the extreme variations are found in brick made from shale, which are conspicuous as making the best as well as the worst kinds of pavers, according to the clay; they usually range, however, from 10,000 to 20,000. The impure fire clay pavers show less variation, or range from 6,000 to 14,000 and usually between 8,000 to 12,000 pounds to the square inch.

Cross Breaking Test.

CROSS-BREAKING STRENGTH.—This test, which is also known as the modulus of rupture, is of considerably greater value than the crushing test, and the methods for making the test are more uniform. This determination might have a direct value if the brick had a very poor foundation; but as actually used on a sand cushion, they rarely break, unless worn out. Like the crushing test, too high a value is apt to be given to it by engineers. It is preferable to the crushing test as a guide, as it is a function of tensile strength, which latter is an important factor of the toughness. The cross-breaking strength ranges from 1,000 to 3,300, and usually amounts to 2,000 to 3,000 pounds per square inch of cross section, as tested between supports set six inches apart and loaded in the middle.

TOUGHNESS.—This is the most vital factor in a paving brick and greatly exceeds all the others in importance. It is the toughness on which depends whether a brick will prove satisfactory in practice, and which of two or more samples will be the more enduring. For the toughness has to resist the severest of the destructive agents on a pavement, or the

*Some tests given in the current literature are self-evident cases of juggling, as they have undoubtedly been selected from the worst samples of rival brickmakers, a too common method of carrying on commercial warfare.

chipping and shattering action that results from the blows of the horses' hoofs and the bumping and abrasive action of the wagon tire.

One of the first methods employed to determine the toughness was to run a heavy roller over the brick to be tested by a mechanical device that could be multiplied indefinitely (St. Louis, 1880). While this duplicated the abrasive wear of the wagon tire, it failed to give the severe impact action of the horses' hoofs.

Rattler. It was early recognized that the foundry rattler or revolving iron barrel offered a simple, rapid, economical and readily available device for testing both the resistance to abrasion and to impact. Also, that the rattler test could be so conducted as to emphasize either the impact factor or the abrasive factor. The rattler was therefore promptly adopted as the best method of determining the wearing value of paving brick. As testing laboratories were not then equipped with them, recourse was had to the nearest foundry, where it is an indispensible tool for cleaning castings because of its severe abrasive action. It was found, however, that there was a marked difference in the length, diameter and speed of foundry rattlers, which greatly affected the results on the same brick. Some engineers also added scrap iron to the charge to increase the severity of the test, while others substituted granite blocks and some added standard brick to obtain an index for comparison. In the early years of the industry there was, therefore, a great range in the method of conducting this very important test and nearly every engineer had his own standard. As a result, it was impossible to compare different tests and there was great confusion. A brick M when tested by one engineer was superior to brick N, while another engineer would reverse this relative rating in consequence of the difference in the methods by which the tests

were made. Thus it was found that the larger the rattler, if run at the proper speed, the more severe was the impact action, or the tendency to break off the edges, knock off the corners and even shatter the brick. If heavy scrap iron or granite blocks were added, the impact effect was greatly accentuated. It was found that there is a certain speed with a given rattler at which the impact or pounding action is a maximum, and any increase or decrease from this decreases this effect, although increase in speed always increases the abrasive or grinding action. If the rattler is too short or the shaft runs through the rattler, the brick are liable to bridge or choke and thereby greatly decrease the effect of both the impact and abrasion action. It is also found that the volume of brick should bear a certain ratio of the volume of the rattler, and any marked increase or decrease in the number of brick over this percentage diminishes the wearing action of the brick on itself by partially protecting or muffling if overloaded, and not giving so many blows if under-loaded. If iron shot or other foreign abraders are employed, it makes a great difference as to the size of the pieces and their relative amount; if the shot is small, it greatly increases the abrasive action, while if the shot are large, the impact factor is greatly augmented. The action of the foreign matter is also augmented if the angles and edges are sharp and decreases as these wear off and become rounded.

To bring about harmony among the engineers and to give brick manufacturers a definite standard by which their brick would be tested, the National Brickmakers' Association in 1895 appointed a committee to thoroughly study the subject and deduce therefrom a standard method of conducting the rattler that would be satisfactory to both the consumer and producer of paving brick. This committee was composed of well-known and authoritative engineers, leading paving brick

manufacturers and acknowledged disinterested clay experts and was composed of: D. W. Mead and Willard Beaban, civil engineers; D. V. Purington, F. B. McAvoy and J. W. Jones, paving brick manufacturers; and Prof. Edw. Orton and W. D. Richardson, clay experts. With them were associated as active participants in making tests and taking part in the discussions, Prof. J. B. Johnson, M. L. Holman and F. F. Harrington, civil engineers, and Prof. H. A. Wheeler, clay expert.

After two years' work in testing several kinds of paving brick under a wide range of conditions, in which the size, speeds, time, volume, percentage and use of abraders were greatly varied in the rattler tests, the committee formulated a method of testing paving brick in 1897* that was promptly adopted by most municipal engineers and brickmakers. Most of the rattler experiments were made by the eminent clay expert, Prof. Orton.

Subsequently the engineer of Geneva, N. Y., Mr. Gomer Jones, suggested a special rattler in which the brick to be tested formed the inner lining and a charge of 150 pounds of castiron cubes 1½ inches square furnished the impact and abrading medium.** While the Jones method seem to be somewhat more sensitive to variations in the brick and to somewhat more closely differentiate different brick, its practical objections have caused it to be regarded unfavorably. The great variations that usually occur in good paving brick from the same kiln renders a delicate refinement unnecessary, especially if the method is more costly and difficult to make. What is wanted is a simple test that will permit a large number to be readily tested with reasonable reliability, so that

*Page 165 eleventh annual report of the National Brick Manufacturers' Association, 1897.

**Page 69, thirteenth annual report, 1899, ibid.

the average value can be derived from a large sample and thus eliminate the errors of sampling.

The work of Prof. A. V. Talbot at the Champaign, Ill., testing laboratory suggested that the standard or N. B. M. A. rattler test should be revised, as he found that it did not sufficiently discriminate against underburned or soft brick. Accordingly another committee was appointed to reconsider the rattler test, and especially to consider the new methods of Jones, Talbot and Orton. This second committee consisted of Prof. J. B. Johnson, Gomer Jones and Prof. A. V. Talbot, civil engineers; D. V. Purington and J. L. Higby, paving brick manufacturers, and Prof. Edward Orton, Jr., and H. A. Wheeler, clay experts. This committee modified the former method by introducing a charge of both light and heavy castiron blocks, which, having a fairly constant weight, volume and character, were found to clearly bring out the weakness of underburned brick. This was the defect of the first method, as it was found that a charge of exclusively soft brick wore one another but little more than hard brick on hard brick. When the iron shot is added, however, the soft brick are rapidly worn or broken and suffer very severely, as they would in practice, as compared with hard brick under the same conditions. The report of this committee is given on page 131, fourteenth annual report of the National Brick Manufacturers' Association, Indianapolis, 1900, and the method they adopted is subsequently given under "Testing." This standard or N. B. M. A. method has been quite generally adopted by both the trade and the profession throughout the United States and Canada, as it gives a method of arriving at the toughness that is just and acceptable to both the producer and consumer. Most of the street departments of our large cities are now equipped with a standard rattler, as are also the public test-

ing laboratories and the yards of the more progressive brickmakers.

As the rattler test is now conducted, the loss in weight, after being rattled an hour, varies greatly according to the inherent toughness of the clay, according to the care given in its manufacture, according to the degree to which it is vitrified and finally according to its shape. When different clays are treated exactly alike, so as to exclusively bring out the individual toughness, the rattler loss is found to range from 5 to 40 per cent and usually between 12 to 20 per cent in brick that have proved to wear well in practice.

The most important and least evident factor in the toughness of a paver is the individuality of the clay itself and which can only be determined by the rattler test or else by use in the pavement. Shales and clays that look to be similar and even have a more or less comparable chemical composition are found to vary greatly in toughness when made into pavers under identical conditions and with equal care. So great is this difference and it is so difficult to predict this factor that no shale or clay should be considered for pavers until this extremely important information has been obtained from a large, working test.

The care taken in manufacture to grind sufficiently fine, to thoroughly screen out all large particles, to pug to a uniform and proper consistency, to so run the brick machine as to secure a bar of uniform, unbroken, non-ragged structure, to repress properly, to handle the wet brick without strain or injury, to dry equally and uniformly, and to finally so fire the kiln as to bring it slowly but progressively to a complete vitrifying heat and to then gradually cool it without air-checking, overburning or rolling the brick, all have great influence on the toughness of a paver. The variations shown in testing different brick from the same kiln demonstrate how important

the manufacturing factors are and how difficult it is to completely control them.

The shape of a brick or block will materially affect the rattler loss according as it is an unrepressed, square cornered paver or whether the sharp edges and angles have been removed by repressing, as the former will quickly chip off in the first fifteen minutes in the rattler test. It has also been found that the ratio of depth to width affects the rattler loss, as the narrower the brick the greater the loss, but as a uniform size has been quite generally adopted, this is not usually an important factor.

To attempt to define a standard for the toughness or rattler loss is unwise and dangerous, as local conditions as to traffic and financial considerations are liable to modify any arbitrary standard. The heavy traffic on the down-town streets in the large cities calls for the toughest brick obtainable, whereas the much less severe travel on the residence streets and alleys in the same city will enable a local brick that is cheaper to make a good record, even though it may not be quite as tough as a distant brick made from a better clay. Many small cities and towns are able to secure the great advantages of a brick pavement by using local pavers that could not stand the expense of shipping in distant brick, even though of a better quality. For the freight is such a heavy charge on long shipments, on account of their great weight (or about 4 tons per 1,000), that it might render the cost more or less prohibitory. The toughest brick will unquestionably always make the best record when laid on the street and prove the most economical in the end at almost any price, but in most cases the tax payers and the paving contractors want the cheapest brick obtainable and the toughness or wearing value is too frequently made a secondary consideration, even when the community can afford the best brick in the market.

The rattler test is an excellent medium for comparing paving brick with granite and, while the latter is usually very much tougher than the average paver, some brick have made as good a test as good granite in the same rattler. Granite is found to vary as much as 600 per cent in the rattler loss, which is partly due to the difference in the granites and partly due to weathering or incipient decay. For granites decay and change into clay on prolonged exposure to the weather, and while this requires a period of time that runs into the hundreds of years, the outcrops or exposed parts of a granite quarry are liable to be considerably softer and less resistant than the material from greater depths. Brick men are apt to credit granite with being a uniformly hard and very tough rock, whereas, there are liable to be marked variations in its paving value. Tests made in Boston* on eighteen different paving brick, in which granite blocks were added to the rattler charge, five of the brick showed a smaller loss than the granite. Another series of tests made at Cornell University** on seventeen different makes of paving brick with trap blocks as a standard for comparison and rated as 1.00, one shale paver showed a loss of only 0.87 and a thoroughly vitrified fire clay brick a loss of only 1.66; the loss of the other brick ranged up to 17.18 and averaged 8.3. As trap is a tougher rock than granite, this is a most encouraging exhibit and augurs well for the future of high grade pavers when engineers insist on the very best quality obtainable and are willing to pay for the enhanced value. For manufacturers can produce a much better brick than the trade is usually willing to pay for. An addition of $3 to $5 per 1,000 to the present costs will permit of so much more care being taken through-

*Engineering News, June 2, 1892.

**Engineering News, April 18, 1895.

out the entire manufacturing process, and especially in the burning and annealing, as to result in a so much superior article as to make this additional investment a measure of true economy. For a brick that still presents a smooth, true pavement at the end of twenty to thirty years is very much cheaper at an advance of $10 per 1,000 over an inferior brick that is so cobbled and worn at the end of ten years that it has to be heavily patched if not renewed.

Influence of the Corners.

When square-cornered brick are tested with those with rounded corners, the former show a much greater loss, as the sharp angles break off readily. This, however, is just what happens in practice, and is a fair comparison as regards brick to brick, but is unfair as a test of the clays, as they should have similar corners to give a reliable comparison.

METHOD OF TESTING PAVING BRICK.

EYE EXAMINATION.—There is no more rapid method of arriving at the merits of a paving brick than by the trained, experienced eye when assisted by the free use of a hand hammer. A critical examination by the eye and hand hammer when combined with proper experience and good judgment, can usually reliably pass on the merits of a brick in a few minutes, while the laboratory tests take hours. But our vocabulary is too limited to make the nice distinctions that are possible to the trained eye and it is difficult to arrive at a satisfactory numerical evaluation. As in most expert work, it is a personal decision that is founded on good judgment, training and experience; and while it leaves little to be desired when backed by integrity for the numerous and rapid decisions of municipal engineering, it is testimony that can be besmirched and impugned when attacked by unprincipled self-interests. As definite standards must be adopted that admit of general use and comparison, and as specific figures

Necessity of Tests.

Inspection Should be at the Kiln

are required that will permit the drawing of specifications and living up to same, a series of tests have been devised which admit of general application and enable definite standards to be attained and lived up to. The necessity of such figures is so well recognized that there are not only numerous testing laboratories scattered all over the country, but the engineering departments of most cities have laboratories that are well equipped to test brick and to furnish specific information when differences of opinion arise between the contractor and inspector about the quality of brick. Usually the inspection of the brick is carried on at the work in the street, when about to be laid, and the condemned brick are a serious expense to the contractor, who is often an innocent sufferer; they have a curious way of disappearing around the corner and reappearing laid in the street. The proper place to in- they are also a menace to the vigilance of the inspector, as they have a curious way of disappearing around the corner and reappearing laid in the street. The proper place to inspect the brick is at the kiln as they are being loaded out, where it can be much more rapidly, easily and safely performed and where there is no such strong incentive to smuggle condemned brick into the work. For even if the paving is done under a maintenance bond, the contractor is usually willing to take risks as to the durability of questionable brick that the cautious engineer would not entertain.

LABORATORY TESTS.—The tests that are made to determine the complete merits of a paving brick are:

I. Density or specific gravity.
II. Absorption or porosity.
III. Crushing strength.
IV. Cross-breaking strength.
V. Hardness.
VI. Rattler test.

The determination of the crushing and cross-breaking strengths requires a large testing machine of at least 150,000 pounds capacity, which is expensive and usually to be found in only well-equiped testing laboratories. But every city and brick plant should have a balance ($5 to $35), hardness scale (50c), and rattler ($25 to $80), with which to make the other tests, which are the most important and only require a moderate outlay if power is available for running the rattler.

While all these tests give information of more or less value, the only test that was regarded as essential and thoroughly reliable in arriving at the wearing value of a brick in a pavement by the Paving Brick Commission of the N. B. M. A. was the rattler test.

DENSITY.—The density or specific gravity test is made on half brick or chips after they have been soaked in water for twenty-four hours to fill the air spaces. A whole brick should not be used, as the water can not usually penetrate into the voids in twenty-four hours when the skin surface is sound and the brick is vitrified. It is preferable to take only a small fragment and weigh accurately on a chemist's* balance to 1 in 10,000, rather than attempt to obtain it by using a half brick and a druggist's scales, as usually employed, which only weigh to about 1 in 300. The density is calculated by the formula:

$$D = \frac{W}{W'-W''}$$

in which D = the specific gravity in terms of water.
W = weight in air before soaking.
W' = " " " after "
W'' = " " water after "

*Excellent balances for this purpose are sold by the chemical dealers for $15 to $35.

Variation in Testing.

ABSORPTION TEST.—The absorption test determines the porosity of a brick and the main value of this test is now recognized as giving the degree of vitrification rather than as a guide to its frost-resisting value. For if the brick is found by the rattler test to be tough enough for a paving brick it is found to have ample strength to resist frost disintegration. immaterial whether the absorption is high or low. There was formerly much confusion in the methods of conducting the test, as some tested the brick as found, while others dried them out for variable times before making the test. Some used whole brick without even breaking the less pervious skin, and a rough balance, while others used chips, which exposed all sides to a freshly broken surface and weighed on a delicate chemical balance. The time of soaking varied considerably, which materially altered the results, as brick are found to increase in weight for thirty to ninety days, though the rate is very slow after the first twenty-four hours, especially if hard burned. The rate of drying out is also very slow and variable, but to a less marked extent than the absorption.

It is, therefore, necessary to adopt arbitrary conditions to obtain results that are comparable and consequently the N. B. M. A. method has been quite universally accepted as the standard.

The specifications for conducting the absorption test according to the National Brick Manufacturers' Association is as follows:*

"1. NUMBER OF BRICK.—The number of brick constituting a sample for an official test shall be five.

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*Report of Paving Brick Commission of National Brick Manufacturers' Association, page 83, T. A. Randall & Co., Indianapolis, Ind.

"2. CONDITION OF THE BRICK.—The bricks selected for conducting this test shall be such as have been previously exposed to the rattler test. If such are not available, then each whole brick must be broken in halves before the test begins.

"3. DRYING.—The bricks shall be dried for forty-eight hours continuously at a temperature of 230 to 250 degrees F. before the absorption test begins.

"4. SOAKING.—The bricks shall be weighed before wetting and shall then be completely immersed for forty-eight hours.

"5. WIPING.—After soaking and before re-weighing, the bricks must be wiped till free from surplus water and practically dry on the surface.

"6. WEIGHING.—The samples must be re-weighed at once. The scales must be sensitive to 1 gramme.

"7. CALCULATION OF RESULTS.—The increase in weight, due to absorption, shall be calculated in per cents of the dry weight of the original bricks."

Or, expressed in the form of a formula, the absorption is calculated by:

$$P = \frac{W' - W}{W}$$

in which P = the porosity.
W = weight before soaking.
W′ = " after "

The usual absorption of good shale pavers ranges from 0.8 to 2.5 per cent, and if they absorb less than 0.8 per cent, they are apt to be brittle from over-burning. The usual absorption of fire clay pavers is 2.0 to 7.0 per cent.

It is interesting to note that after the N. B. M. A. committee prepared the preceding specifications they drew up the

following resolutions, with which, however, some engineers, from lack of breadth and experience, will not agree:

"Resolved, That, in the opinion of this Commission, any paving brick which will satisfy reasonable mechanical tests (rattler) will not absorb sufficient water to prove injurious in service. We therefore recommend that the absorption test be abandoned from all official tests as unnecessary, if not absolutely misleading."

Objections to Johnson's Methods.

CRUSHING TEST.—As previously stated, this test is now quite generally abandoned, as it is found to be too unreliable, especially as the over-burned, brittle brick usually show the greatest strength. When the test is made, the method of making it has such a very important influence on the results that the Paving Brick Commission of the N. B. M. A. endorsed Prof. J. B. Johnson's method, which is as follows:

1. The crushing test should be made on half bricks, loaded edgewise or as they are laid in the street. If the machine is unable to crush a half brick, the area may be reduced by chipping, keeping the form as nearly prismatic as possible. A machine of at least 100,000 pounds capacity should be used, and the sample should not be less than four square inches in cross-section.

2. The upper and lower surfaces should be ground to true, parallel planes, if possible. If not, they should be bedded in plaster of paris, while in the testing machine and allowed to harden ten minutes before the load is applied.

3. The load should be uniformly increased until ruptured.

4. An average of five or more different brick shall constitute a standard test.

CROSS-BREAKING STRENGTH.—The cross-breaking strength has been universally determined by supporting the brick between two hardened steel knife edges set six inches apart, and applying the load in the center by another knife

edge, all the edges being rounded. From this the modulus of rupture (R) is determined by the formula:

$$R = \frac{3\ W\ l}{2\ b\ h^2}$$

in which W = breaking load in pounds per square inch.
l = length between supports.
b = breadth of brick.
h = height " "
R = modulus of rupture in pounds per per sq. in.

In the specifications adopted by the N. B. M. A. Commission, it is stipulated that the knife edges be rounded longitudinally to a radius of 12 inches and transversely to a radius of 1/8 inch, and that the average of ten or more brick shall be a standard test.

Moh's Scale.

HARDNESS.—The hardness has hitherto been rarely determined, and then by grinding the brick on a polishing table, and taking the amount ground off as a measure of the hardness. As this grinding action introduces the factor of toughness as well as hardness, it is a very unsatisfactory test, and is now seldom made. A simple, quick test that correctly gives the hardness is Moh's scale of hardness, which is the principal tool of the mineralogist. In this scale, which runs from No. 1 or talc, which can be readily scratched by the fingernail, to No. 10 or the diamond, the hardest substance known, only Nos. 6 and 7 interest the tester of paving brick, as brick are too soft for pavers that are not as hard as 6, and most pavers are between 6.5 and 7.0. No. 6 is feldspar, or the white to pink mineral that constitutes about 75 per cent of the granites, and No. 7 is quartz, the hardest of the common minerals, which is the colorless, glassy constituents of granites.

Mode of Testing.

In applying the tests, a sharp edge or angle should be tried on a smooth face of the object being tested, and a firm, strong

pressure applied. Substances of equal hardness scratch each other with equal facility, while if there is a difference of 0.5, as, say, 6.0 and 6.5, the substance that is 6.5 will be barely scratched by the 6.0, but it will readily scratch 6.0; a substance that is 7.0 in hardness is not affected by 6.0, while it very readily scratches 6.0. Practice is needed to make fine distinctions, lacking which the determination should not be attempted closer than 0.5, and the white dust that results from the scratching should be rubbed off before deciding which is the harder substance.

RATTLER TEST.—As previously stated, the great confusion that prevailed in the early days from the great difference in the methods of conducting this very important, vital test on paving brick was eliminated by the painstaking and elaborate work of the Paving Brick Commission of the National Brick Manufacturers' Association, which was published in 1897. As subsequent work showed that it could be reasonably improved in sensitiveness and made more reliable in differentiating between separate loads of hard and soft brick, the specifications were revised in 1901, which are herewith given as the standard method of testing paving brick:

REVISED N. B. M. A. STANDARD METHOD OF CONDUCTING THE RATTLER TEST.

1. DIMENSIONS OF RATTLER.—The standard rattler shall be 28 inches in diameter by 20 inches long, measured inside the chamber. Other machines may be used within the limits of 26 to 30 inches in diameter and 18 to 24 inches long, of which a special note is to be made in the report. Longer rattlers must be reduced to proper length by the insertion of an iron diaphragm.

2. CONSTRUCTION OF RATTLER.—The rattler may be driven by trunions at one or both ends, or by rollers beneath,

but no shaft shall pass through the chamber. The cross-section of the rattler shall be a regular polygon with fourteen sides, and the heads shall be gray castiron that is not chilled or case hardened. The staves shall preferably be steel plates, as castiron peans and ultimately breaks with a space of one-fourth inch between the staves for the escape of the fine waste.

3. COMPOSITION OF THE CHARGE.—A charge is to consist of only one kind of brick at a time and an iron abrasive. The number of whole brick used for a charge to approximate 1,000 cubic inches, or 8 per cent of the contents of the rattler (usually nine to eleven brick). The abrasive charge is to consist of 300 pounds of two sizes of shot made from machine castiron, of which 75 pounds (25 per cent) shall be the large size and 225 pounds (75 per cent) the small size.

4. SIZE OF SHOT.—The large sized shot shall weigh about 7½ pounds and be 2½x2½x4½ inches long, with slightly rounded edges. The small shot to be 1½-inch cubes, weighing about ⅞ of a pound, with square corners and edges. The individual shot are to be renewed when they have lost 10 per cent of their weight.

5. REVOLUTIONS OF THE CHARGE.—The rattler is to make 1,800 revolutions at a speed of 29 revolutions per minute, with a permissible range of one revolution more or less than this rate. The belt power should be sufficient to run the rattler at the same speed, whether loaded or empty.

6. CONDITION OF THE CHARGE.—The brick are to be thoroughly dried before making the test.

7. CALCULATION OF RESULTS.—The loss is to be calculated as a percentage of the weight of the dry brick and an official test is to be the average of two different, complete charges.

EVALUATION OF THE TESTS.—Since the work of the N. B. M. A. Commission has shown that the rattler test is the only safe, reliable, satisfactory method of arriving at the wearing value of paving brick, they are now rated and classified by a simple comparison of the rattler results, that brick being regarded as the best which shows the least loss in the rattler. It is, of course, highly essential that they are all tested by the standard method, or at least under identical conditions.

When the absorption, crushing and cross-breaking tests were formerly made, it was not so simple to decide which was the best brick, as the brick that made the best record in one test was not apt to be equally as good in the other tests. It was therefore necessary to adopt arbitrary values as to the relative importance of the different tests, and by formulas calculate the rating of a brick. Formulas for this purpose were prepared by Prof. Ira Baker in 1891 ("Brick Pavements," Indianapolis, Ind.), by the City of St. Louis in 1894 ("Engineering News," July 26, 1894), by Prof. J. B. Johnson in 1895 ("Engineering News," April 18, 1895) and by the writer in 1895 ("Vitrified Brick," Indianapolis, Ind., first edition, page 61). As these formulae were seldom used in practice and are now rendered obsolete by the work of the N. B. M. A. Commission, the student of history is referred to the above originals for the details of same.

Variations in Paving Brick.

UNIFORMITY OF RESULTS.—In testing brick at least five specimens of each lot or kind should be tested, and preferably ten, and the results averaged. If the samples are taken from different kiln runs and made at different times, it adds greatly to their reliability if the individual tests closely agree; but if the results vary greatly, such a clay is open to suspicion until careful resampling and testing shows whether it is due to careless sorting or to manufacture. The best brick

vary from 15 to 30 per cent in the tests, while inferior brick exceed 50 per cent, and this range is a very valuable check on the care in making the brick, and on the sorting in loading. To illustrate the variations that usually occur in paving brick, the following table gives results obtained by the Civil Engineering Department of the University of Illinois from samples selected from twenty-four paving brick plants in Illinois, Indiana, Ohio, Missouri and Kansas by the Illinois Geological Survey:

TESTS OF WESTERN PAVING BRICK

Including Underburned and Overburned Samples

Name of Brick	Grade of Brick.	Average Total % Loss of Two Charges at End of 450 Rev.	900 Rev.	1350 Rev.	1800 Rev.	Per Cent Absorption	Cross Breaking Str'ngth Per Sq. In	Crushing Strength Per Sq. In.	Size of Brick in Centimeters
Albion, Ill	Soft	18.5	29.5	38.4	46.2	8.9 to 12.0	690 to 1870		22 5x10.5x8
" "	Alley	11.3	17.5	21.2	24.6	2.1 to 4.1	830 to 2810	3600 to 4870	21x9.5x8
" "	No. 1 paver	12.7	19.0	22.5	24.9	0.5 to 1.7	1860 to 2550	3000 to 6420	21x9.5x8
" "	Overburned	11.1	18.6	24.1	26.4	0.2 to 1.2	2070 to 3060	2670 to 4280	21x9.5x8
Alton, Ill	Soft Burned	17.4	28.6	40.0	46.1	8.0 to 12.6			22x10x7
" "	Alley	13.3	21.5	28.2	33.9	4.0 to 7.2	1240 to 1960	2820 to 5070	21.5x9.5x7
" "	No. 1 paver	8.4	11.5	14.1	15.8	0.5 to 1.0	2080 to 3100	5600 to 10800	21.5x9.5x7
" "	Overburned	9.4	16.2	21.8	27.0	0.8 to 1.5	1200 to 1680	......	......
Atchison, Kan	No. 1 paver	......	......	......	28.0	......	......	......	20x9.5x6.7
" " "	do	13.6	19.5	23.9	27.9	......	......	......	......
Barr Clay Co., Streator, Ill	Soft	14.5	20.9	25.4	29.5	6.4 to 8.3	1379 to 1959	6860 to 10000	21x9.5x8.5
" " " "	Alley	10.2	15.4	19.0	21.8	0.8 to 1.2	2200 to 2810	8360 to 17700	......
" " " "	No. 1 paver	10.3	13.9	16.7	18.4	0.5 to 1.1	1840 to 2580	8900 to 18500	......
" " " "	Overburned	9.1	14.5	18.7	22.0	0.7 to 1.0	2520 to 3460	6780 to 10300	21x10x8
Brazil, Ind	Soft	28.9	45.1	56.8	67.1	11.1 to 16.3	255 to 1080	......	24x11x8.5
" "	Alley	13.6	20.1	25.3	29.8	1.6 to 4.2	1280 to 1980	......	23x10x8
" "	No. 1 paver	13.5	20.1	24.5	28.1	1.7 to 1.9	1966 to 2540	......	22.5x10x8
" "	Overburned	14.5	23.5	30.8	36.7	2.0 to 3.5	550 to 1260	......	23.5x10.5x8
Caney, Kan	......	9.7	17.3	22.0	25.7	2.2 to 4.5	1090 to 3000	......	22.5x10.5x6.5
Clinton, Ind	Soft	16.1	26.0	33.6	41.6	6.1 to 14.0	945 to 1630	1440 to 5000	24.5x11x9
" "	Alley	14.5	22.7	29.0	34.7	5.7 to 9.1	1000 to 1470	......	23.5x10.5x8.8
" "	No. 1 paver	12.9	19.6	26.2	31.5	1.0 to 2.5	925 to 2040	4050 to 7800	23.5x10.5x8.5
" "	Overburned	14.4	21.6	27.5	31.6	0.9 to 1.4	530 to 3350	4740 to 5900	23.5x10.5x8.5
Coffeyville, Kan	Brick	......	......	......	13.7	0.0 to 1.6	1918 to 2844	5000 to 7300	21x10x5.5
" "	......	5.6	8.5	10.9	12.8	......	......	......	......
" "	No. 1 block	......	......	......	15.0	......	......	......	21x10x8

Danville Brick Co.............	Soft..........	19.8	29.8	38.9	46.7	....	....	....	22.5x11x8.5
" " "	Alley..........	12.7	19.8	25.1	30.2	2.9 to 7.6	1420 to 1980	4100 to 6700	22x10x8
" " "	No. 1 paver...	9.1	13.9	17.6	20.8	1.8 to 8.2	420 to 1460	2550 to 4000	21x10x8
" " "	Overburned..	9.8	17.2	23.3	28.4	1.0 to 2.9	805 to 2300	5100 to 7830	22x10x8.5
Edwardsville, Ill...............	Soft..........	17.8	28.7	37.0	44.9	8.7 to 10.7	....	....	21.8x11.8x7.8
" "	Alley..........	12.6	19.5	24.8	28.7	2.8 to 7.4	....	....	21.2x10.4x7.0
" "	No. 1 paver...	7.8	12.5	16.8	19.4	2.4 to 2.9	....	....	....
" "	Overburned..	8.2	12.2	15.2	18.1	0.8 to 1.9	....	....	20.6x10.4x7.0
Kansas City, Mo., Diamond...	No. 1 paver...	14.8	20.9	24.9	27.9	0.5 to 1.0	1260 to 2820	....	20.5x9.5x6.5
Lawrence, Kan.................	No. 1 paver...	10.4	15.2	18.8	22.9	1.2 to 2.5	1470 to 2600	....	....
" "	No. 2 paver...	8.7	11.0	16.0	18.6	0.8 to 1.0	1410 to 2780	....	20x9.5x6.5
Poston B, Crawfordsville, Ind.	Soft..........	14.8	23.6	31.9	39.5	7.9 to 11.2	575 to 1040	3600 to 4280	23x10x9
" " " "	Alley..........	8.9	14.8	18.0	21.7	4.8 to 7.7	840 to 1880	6800 to 9700	23x10x9
" " " "	No. 1 paver...	6.4	9.7	12.4	14.8	1.4 to 3.2	1660 to 2580	8020 to 11600	22.5x10x9
" " " "	Overburned..	6.1	9.8	11.8	13.7	0.6 to 1.0	1020 to 2520	6900 to 12800	22.5x9.5x9
Pittsburg, Kan	No. 1 paver...	8.4	12.8	15.1	17.1	1.7 to 8.8	1870 to 2940	7700 to 14600	20.5x9.75x6.5
Purington block, Galesburg, Ill	Soft..........	7.8	13.4	18.2	22.8	5.4 to 8.1	....	....	21.5x10.2x8.9
" " " "	Alley..........	7.5	11.7	15.4	18.8	3.8 to 4.9	....	....	21.5x10.2x8.9
" " " "	No. 1 paver...	5.8	9.1	11.6	13.8	0.0 to 0.9	....	....	20.9x10.2x8.9
" " " "	Overburned..	8.4	12.9	16.5	20.8	0.4 to 1.8	....	....	20.9x10.2x8.9
" " " "	Soft..........	14.7	23.7	31.7	38.6	4.9 to 7.8	....	....	21.5x10.2x8.9
" " " "	Alley..........	9.9	16.6	21.9	26.6	3.7 to 8.8	....	....	21.5x10.2x9.5
Springfield, Ill................	....	.....	.....	.....	19.8	....	....	....	....
" "	Soft..........	19.7	30.6	38.2	45.2	11.7 to 12.7	750 to 1260	1150 to 2840	22x10 5x7
" "	Alley..........	9.2	14.5	17.0	19.9	4.0 to 6.0	1920 to 2960	4100 to 6170	21x9.5x6.7
" "	No. 1 paver...	9.9	14.2	16.9	19.1	1.1 to 1.2	1800 to 2820	....	21x10x6.5
" "	Overburned..	14.8	18.9	.....	.....	0.5 to 0.7	625 to 3530	3020 to 4800	21x10x6.5
St. Louis, Mo., hydraulic......	No. 1 paver...	.....	.....	.....	17.5				21x10x7
" " "	No. 1 paver...	7.9	12.2	14.2	15.9	0.8 to 1.2	860 to 3480	6940 to 11500	....
Streator Paving Brick Co......	Alley..........	14.7	20.1	25.2	29.0	0.9 to 5.1	....	....	20.9x10.2x5.7
" " " "	No. 1 paver...	10.7	16.8	21.6	24.8	0.5 to 0.5	....	....	20.8x10.2x5.7
" " " "	Overburned..	19.6	15.5	18.4	21.9	0.0 to 0.5	....	....	20.8x10 2x5.7
Terre Haute, Ind...............	Soft..........	23.1	32.8	40.8	46.5	7.8 to 10.2	875 to 1890	....	22x10x8.5
" " "	Alley..........	19.9	28.2	32.9	35.7	1.2 to 3.7	855 to 2600	....	21.5x10x8

TESTS OF WESTERN PAVING BRICK---Continued.

Name of Brick	Grade of Brick	Average Total % Loss of Two Charges at End of				Per Cent Absorption	Cross Breaking Str'ngth Per Sq. In	Crushing Strength Per Sq. In.	Size of Brick in Centimeters
		450 Rev.	900 Rev.	1850 Rev.	1800 Rev.				
Terre Haute, Ind	No. 1 paver	22.6	29.8	35.8	39.4	0.6 to 1.4	1800 to 2870	3580 to 7250	21.5x10x8
" " "	Overburned	19.0	26.7	32.0	36.1	0.6 to 1.0	1100 to 3130	1570 to 3520	22x10x8.5
Topeka, Kan	Soft				33.0				6.5
" "		14.1	20.5	26.0	29.6	0.9 to 1.6	1840 to 3040		
Wabash Clay Co., Veedersburg Indiana.	Soft	26.5	32.7	45.6	53.5	9.3 to 10.7	285 to 765	1890 to 4500	23.5x10x9
" " " "	Alley	11.8	17.6	24.2	28.1	6.7 to 8.9	755 to 1300	3020 to 5440	23.5x10x9
" " " "	No. 1 paver	10.2	15.0	18.5	20.2	3.5 to 4.2	570 to 1990	2480 to 6230	22.5x9.75x8.5
" " " "	Overburned	12.5	18.7			1.0 to 1.9	820 to 1760	5350 to 9450	23x10x9
Western Brick Co. Danville, Ill	No. 1 paver	8.4	13.4	17.3	20.8	3.9 to 4.7	1364 to 1924	3580 to 6750	23x10x8.5
" " " " "	No. 1 paver				21.2				
			600 Rev.	1200 Rev.	1800 Rev.				
Imperial, Canton, O	No. 1 paver				14.2				22x10x9
" " "	No. 1 paver		8.7	12.2	14.8				
Moberly, Mo			13.9	20.9	26.8	2.5 to 4.3	1890 to 2380		20x9x8.5
Nelsonville, O	No. 1 paver				16.9	1.3 to 1.9	1560 to 2100	2640 to 4950	23.8x10x8.2
"	No. 1 paver		9.0	13.9	18.2				
Portsmouth, O	No. 1 paver				17.8				22.75x9.9x8
"	No. 1 paver		9.8	14.8	18.6	2.1 to 2.2	1980 to 3040		
Royal, Canton, O	No. 1 paver				15.8				21.8x10x9
" "	No. 1 paver		10.8	10.7	16.7				

For fuller information as to the details of the above tests and variations in the samples, see pages 81 to 131, Volume 9, Illinois Geological Survey, Urbana, Ill., 1908.

USES OF VITRIFIED BRICK.

In addition to having outdistanced its rivals as the most popular material for a good street pavement, vitrified brick is also very extensively used for sewers, buildings, sidewalks, foundations and chemical purposes.

Uses of Vitrified Brick.

SEWERS.—On account of its exceptional hardness, vitrified brick is so greatly superior to common brick for sewer construction that it has very largely replaced it, at least for facing the sewer. Its low porosity and high strength also add additional merit for this rapidly growing use of vitrified brick. The severe scouring action of the sand that is swept through the sewers by storm waters, which is so destructive when common brick is used (especially where the grades are considerable, as in hilly cities) scarcely affects vitrified brick and very greatly prolongs the life of the lining of the sewer, if it does not entirely remove the need of relining.

When our cities are paved with hard pavements and the use of macadam is abandoned, the cleaning of our streets will be revolutionized if the sewers are lined with vitrified brick. For then it will be safe to use the hydraulic system for cleaning the streets, which the present soft lining of our sewers—at least the old, main or trunk sewers—usually prohibits, as the scour would destroy them. Under the hydraulic system, the cleaning would not only be much more thorough, efficient and rapid, but also much cheaper and entirely free from the unhealthy dust. A small hose crew, with the power furnished by coal at the city water works, would replace our present large gangs of men, sweeping machines and dirt carts. The heavier demand for water that this flushing system of cleaning would create would naturally require it to be done at night when the consumption is small, although this is the only time that the cleaning of the streets should be tolerated.

BUILDINGS.—The use of vitrified brick for building is

Macadam or broken stone, including telford, novacutile, etc.

Wood blocks, including sawed and round, prepared and unprepared.

Asphalt and bitulithic pavements.

Granitoid (for alleys) or concrete.

Cobble stones, or small boulders or rounded stones.

Stone blocks, or dressed, rectangular blocks of hard stone, as granite, trap, sandstone, etc.

Macadam.

MACADAM.—The macadamized road is a very elastic term that covers the rural road on which there may be only four inches of broken stone to the high grade telford that has a 9-inch foundation of rubble or coarse rock, a 4 to 6-inch subbase of smaller rock, a 2 to 4-inch cover of 2-inch rock and a 2-inch top dressing of ½ to 1 inch rock or gravel with a suitable binder. There is consequently a great range in the cost, although in almost all cases they are the cheapest of hard pavements. Whether well built or cheaply built, they all have the common weakness of requiring incessant patching or repairing and they are dusty in dry weather and muddy in wet weather unless maintained in an ideal condition that is seldom seen. When frequently and lightly sprinkled, they make ideal park roads if only light driving is permitted and they are properly drained. Too frequently, where the sprinkling is done by contract, they are over-deluged and rendered muddy as well as injured to reduce the number of trips, yet if it is hot or windy, they are dusty again before the next trip of the water wagon.

Under heavy traffic the surface wears away rapidly, while ruts and chuckholes increase with remarkable rapidity. This constant resurfacing and filling up of the ruts calls for a liberal maintenance outlay, especially as the worn out (crushed) old surface has to be scraped off before it is renewed with another top dressing. To show how heavy the wear is on a ma-

cadamized street that was used moderately, it was found on one of the side streets of St. Louis where a hard limestone macadam was employed that the accumulation of the broken stone hauled on it for repairs would have filled the street to above the second floors of the houses if the worn out surfaces had not been partially blown away as dust, partially washed down the sewers as an impalpable mud and partly hauled off as scrapings.

On account of their low cost, the macadam road still constitutes the largest mileage in this country, as it is usually the first step forward from the dirt road, which latter in America is usually a right of way that is generally impassable for two to four months in the winter and early spring from the heavy mud and is quite frequently almost prohibitive in the summer from the excessive dust.

As the wealth of a community increases and especially when it appreciates that the best is the cheapest, the macadam road is nearly always replaced by a brick pavement.

The rapid growth in the use of the automobile has been very severe on macadamized roads, as their high speeds are very trying on the binder, loosening it and starting the destruction of the pavement. This has been partially mitigated by oiling the roads with petroleum residuum, which also greatly alleviates the dust nuisance, but the oil is trying on the rubber tires.

Wood Block Pavements.

WOOD PAVEMENTS.—Almost every city in this country has tried the wood block—both round and sawed—been highly pleased with it for a while, but after laying perhaps quite a large mileage, have later almost invariably condemned it. Later on, under a new name or material or different preparation, the wood block has been laid again and subsequently severely condemned when the repair period arrived. This experience has been frequently repeated in many of our large

cities. Formerly the wood pavement was usually cheap and for the first two to four years of its life, if well laid, it made a fair pavement and it is always noiseless. But when wear and decay set in it is so difficult to keep in repair that it is usually abandoned as a hopeless, rough, soggy street until forced to replace it with a more durable pavement. While the unprepared wood lasts three to seven years, according to the wood and the thoroughness of the inspection, when it is properly creosoted its life can be lengthened to five to eight to ten years, according to the travel. Since wood has so greatly advanced in price, the former attractive cheapness of the wood pavement has largely, if not entirely, disappeared and it is now rarely laid without being creosoted or otherwise protected from decay.

As the density of the traffic increases in our large cities, the noise becomes more and more serious and around such buildings as court houses, schools and churches the elimination of the noise is sometimes so important that wood blocks are again being used in spite of the fact that they have to be renewed every five to seven years. For it is the only hard pavement that is noiseless and clean. In London, England, where the traffic density is greatly in excess of any other city in the world, wood pavements have been regarded as a necessity for many years, as the roar of the wagon traffic would otherwise be unbearable. They employ a very hard imported wood, which is sawed to make a close fitting pavement, and its life is usually five to six years.

Asphalt and Bitulithic.

ASPHALT AND BITULITHIC.—An asphalt pavement makes an ideal sanitary street, as the surface is an unbroken sheet about two inches thick of impervious asphaltic mixture and for this reason asphalt has been largely used in the dense tenement districts of New York City. Because it presents an unbroken surface, its tractive resistance is very low during

the cool weather, but in very hot weather it softens more or less and is not so satisfactory. It gives a very poor footing to the horses and when wet it becomes so slippery as to be almost prohibitive for heavy teaming.

It is an expensive pavement, as it requires a 6-inch concrete foundation and the asphaltic sheet is a complex of predominant limestone dust (as a filler), sand, asphalt and petroleum residuum that requires special skill to properly proportion and lay. If overheated, the asphalt is injured and if insufficiently heated it does not stand the weather, while the asphalt itself is an uncertain compound that not only varies with every deposit, but often in the same deposit. To properly lay a first-class asphalt pavement that will not crack in winter nor soften in hot weather is an art that no city street department, with its political complications, can hope to do, so that the work is usually done on contract by specialists who ship their crews from city to city.

As it is difficult in such an uncertain complex to secure a uniform mixture, asphalt pavements usually wear rapidly into holes and bad spots that should be looked after every month or two, but these can be easily cut out and the surface renewed by a skillful crew of specialists.

In bitulithic pavements, gravel or finely broken stone soaked with asphalt are substituted for the complex mixture of sheet asphalt and similarly rolled to a smooth, uniform surface by steam rollers. While not as expensive as sheet asphalt, it has not proved as durable, and it requires constant patching to remove the holes and ruts.

Granitoid.

GRANITOID.—Granitoid or concrete is occasionally used for alley pavements where the traffic is very light. While it makes a very clean, sanitary pavement, it gives a very poor foothold and rapidly wears into holes and ruts. It is scarcely to be considered seriously today, but if the motor driven ve-

hicle should drive the horse out of business in the cities, it would then rapidly loom up as a very important paving material, when only a rubber tire would be the principal destroying agent.

Stone Pavements.

COBBLE STONES.—The cobble stone or rounded boulder pavement is nearly a thing of the past, except on very steep grades and in a few ultra conservative cities like Baltimore. They give an excellent foothold, are usually cheap and easily repaired, but otherwise they possess a maximum of faults, not the least of which is their extreme noise. A lone, empty cart jolting over a cobble pavement makes such a noise that should cause their abolition in any town that does not have to contend with grades of over 8 to 10 per cent. The eastern cities formerly had a very large mileage of these noisy pavements that are so difficult to clean, but they have been more or less completely replaced by asphalt, stone blocks or brick in the more progressive places.

STONE BLOCKS.—Stone blocks are very largely used in the down streets of our large cities, as they are capable of successfully withstanding the heaviest traffic and are the most durable pavement known if a hard rock is employed. Usually granite or trap are employed, which can be readily trimmed into regular, quite uniform blocks that have a toughness that assures a very long life under the heaviest traffic. Sometimes local stone is employed that is much less durable, as sandstones and limestones, which, while they vary greatly in their wearing ability, never approach the durability of the compact feldspathic rocks like granite and trap.

While the cost of a Belgian or stone block pavement varies greatly according to the stone employed and the distance it has to be shipped, they are usually the most expensive pavement to put down, although their long life and insignificant

maintenance expenses make them very economical to maintain.

PRINCIPAL FACTORS OF A PAVEMENT.

The principal factors to be considered in the selection of a pavement are as follows:

1. First cost.
2. Maintenance.
3. Ease of traction.
4. Foothold for the horses.
5. Cleanliness and ease of cleaning.
6. Noise.
7. Ease of repairing.
8. Sanitary value.

While the relative value of these different factors will largely follow the order as given, local conditions will more or less modify all of them and various authorities will materially differ in the relative values to be given to each factor.

Comparing the merits of vitrified brick with other paving material in meeting these conditions, we have the following broad considerations:

First Cost.

FIRST COST.—The first cost is by far the most important factor in the majority of towns and cities of moderate size, where the assessed value of the property often comes too uncomfortably close to the value of the street improvements. Even in our large cities, where the much higher value of property eliminates this trouble, many short sighted tax payers are more eager for the cheapest than the best pavement.

Comparing vitrified brick with the other pavements, we find that it is much cheaper than stone blocks, wood or asphalt, but it is usually considerably higher than macadam. These are broad generalizations and when specific figures are used, it must be remembered how greatly they fluctuate in

the same place, according as the times, competition, labor and other conditions vary, while a very great range occurs when different places are compared.

Comparison of Costs.

Usually the cost per square yard of first-class pavements will fall within the following limits:

USUAL PAVEMENT COSTS PER SQUARE YARD.

Stone blocks—\$2.20 to \$2.50 (up to \$3.50).
Creosoted wood—\$2.10 to \$2.50 (up to \$3.50).
Asphalt—\$2.00 to \$2.50 (\$1.60 to \$3.15).
Vitrified brick—\$1.20 to \$1.75 (\$1.00 to \$2.00).
Macadam and telford—75c to \$1.50 (40c to \$2.00).

Maintenance.

MAINTENANCE.—The maintaining of a pavement in first-class condition, or the annual cost for repairs, is so intimately associated with the durability of a pavement that they can be considered as one question. It is a most elastic, unsatisfactory matter to discuss, as, while some very elaborate costs are to be found in current literature, some of which emanate from engineers, that entitle them to careful consideration, the standards differ so greatly in different cities and in the same city under different administrations as to make comparisons very unsatisfactory and often highly misleading. Thus one city will regard its asphalt streets as being well maintained if they are patched twice a year at a cost of 2 cents to 5 cents per square yard, while another city has the repair crew go thoroughly over them at least once a month, or oftener if necessary, and spends 15 cents to 25 cents per square yard annually. One city will have the repairing done by the street department that in another place is done by contract under inspectors for probably considerably less than half the expense.

Where a pavement is laid with a five or ten year maintenance clause, the difference in opinion between the contractor and the city engineer as to when repairs are necessary is often highly amusing, and not unfrequently no repairs are

made whatever, in spite of carefully drawn specifications and heavy bonds.

The standards of taste and the wealth of different communities vary so greatly that what would be regarded as a satisfactorily maintained street (especially macadam) in one place would not be tolerated in another.

Repair costs should therefore be considered only in the broadest way and given only tentative values, unless all details and local conditions of a specific case are fully given.

A good granite block laid in a first-class manner is almost exempt from any repairs for ten to twenty years if not disturbed for pipe laying, etc.; but as almost every city street is dug up at least once a year for laying or repairing sewers, water, gas, steam or ammonia pipes, electric wire conduits, car tracks, etc., and as the surface is rarely, if ever, properly relaid, even granite pavements need occasional repairing, which is mainly an effort to restore the original surface. The outlay is usually only 1-10 to 2 cents per square yard annually, which makes Belgian or stone pavements pre-eminently the most economical to maintain. If the stone have been quarried from, at or near the surface, "weathering" or decaying may have so softened apparently sound granite that it will wear out in ten to twenty years; but if obtained from a depth sufficient to preclude weathering action, good granites, traps and other felsitic rocks should last from twenty-five to fifty years under heavy traffic.

A cobble stone pavement will have approximately half the life of a stone block pavement and require more attention in resetting them to hold the boulders to grade.

Brick pavements are almost as free from repairs as granite blocks for the first seven to fifteen years, according to the quality of the brick and the amount of traffic. After that, occasional patching is required to replace broken and worn out

brick, which is an insignificant outlay if promptly done, but if allowed to wear into ruts, becomes decidedly appreciable, or from $\frac{1}{2}$ to 3 cents per square yard annually. The ultimate life of a high grade brick pavement is difficult to state, as it varies so greatly with the quality of the brick, the care with which it is laid and the density of the traffic it bears; usually it ranges from ten to thirty years.

Wood pavements are also very free from repairs for the first 50 to 65 per cent of their life; then the soft, decaying, imperfect blocks begin to show rapidly and each one starts a chuckhole that soon causes the destruction of the adjoining blocks, even if sound. If it is patched with new blocks, the latter are so much more resistant than the older, softer blocks that each patch soon doubles the number of chuckholes, as one forms on each side of the patch. Patching soon becomes so discouraging that it is usually abandoned and the street is left to its rough, rutty, dirty, absorbent, rapidly retrograding condition until it becomes so bad that the wooden blocks are removed and usually replaced by either brick or asphalt. For the last year or two in the life of a wooden pavement so disgusts the abutting property owners that they will rarely tolerate another wooden pavement.

Asphalt and bitulithic macadam are by far the most expensive to maintain. For the 2 to 3-inch surface of sheet asphalt or bitulithic macadam constantly wears into holes that rapidly widen if not promptly repaired. To maintain an asphalt pavement free from holes, the repair gang should go over it at least once a month, but as this is usually done by contract, most pavements are allowed to go at least six months or longer, by which time the area to be patched is quite an important percentage of the pavement. The cost of patching per square yard will vary greatly according to the skill, care and efficiency of the repair gang. Published state-

ments as to the cost differ so greatly as to make it impossible to make comparisons unless intimately acquainted with the local conditions. Statements made by reliable engineers range from 1 to 15 cents per square yard of pavement per annum, but probably 5 to 12 cents is more nearly the average.

The bitulithic needs more frequent repairs, but as they are more cheaply made than with the sheet asphalt, the cost of maintenance will fall within the above figures.

EASE OF TRACTION.

Ease of Traction.

The power required to haul a given load over the different pavements varies greatly, and while this is a more important factor with business vehicles, it is also a factor with pleasure outfits. With this should also be considered the relative wear and tear of the harness and rig, which will be found to approximately vary as the tractive resistance, especially with automobiles. Asphalt leads in this respect, but is closely followed by brick and wood, when the latter is in good condition. Stone blocks are much inferior, while cobble cobble stone pavements are atrocious.

Macadam varies greatly, according to the condition in which it is maintained. If kept damp and free from ruts, it is superior to granite; but if it ranges from a very dusty to muddy condition, it is decidedly inferior to granite. A relative comparison of the traction of the same load over different pavements as well as dirt and loose is given by Rudolph Hering, the eminent civil engineer, as follows:

COMPARATIVE HAULAGE OF A GIVEN LOAD ON:

Iron rails	1 horse
Sheet asphalt (good condition)	1.7 horse
Brick	2.25 to 2.75 horse
Granite blocks	3.3 to 5. horse
Wood	5. to 6. horse

Good macadam....................................8. horse
Cobble stones.............................7. to 13. horse
Earth..20. horse
Sand...40. horse

FOOTING.—A sure footing for the horses and freedom from slipping is an important factor of a pavement, in which asphalt and rectangular wooden blocks are very defective. The joints of brick and granite blocks hold the calks of a horse's shoe and are therefore very satisfactory. Macadam and cobble stones are more efficient and on very heavy grades, or over 10 per cent, are the only pavements that should be used. Brick and granite can be used up to 10 per cent grades, but asphalt or wood should not be used if the grade exceeds 3 per cent. For automobile service, this factor disappears.

CLEANLINESS AND EASE OF CLEANING.

Cleanliness. The hard pavements, or stone, brick and asphalt, do not produce through wear any dirt that is of consequence and wood is also practically free from it until, through decay, it gets into a soggy, spongy condition. Macadam, on the contrary, unless maintained in an ideal condition of dampness that is rarely seen and protected from heavy traffic, produces so much dust in dry weather and is so muddy in wet weather or from imperfect sprinkling that it should not be tolerated in large cities where the value of the land justifies the best pavements. The cleaning of macadam pavements is also very costly, as it has to be done by hand labor, as sweeping machines or the hydraulic systems destroy it. The hard pavements can all be cleaned by sweeping machines, but the results are not satisfactory on stone pavements on account of their roughness and the large joints, while the wear is heavy on the brooms of the machine. The flushing or the hydraulic systems (which are the most efficient and cheapest) can be

used on all hard pavements, but the water shortens the life of asphalt by slowly disintegrating it through a solution of the binding oils.

Noise.

NOISE.—This is a very important factor in large cities, but its importance will vary with local conditions. It is not so serious in a manufacturing community as it is in the residential quarters and especially about schools, churches, court houses, etc. All the durable pavements are open to more or less criticism, although in most cases this factor is subordinated to the much more vital questions of cleanliness and durability. Wood makes a pavement that is practically noiseless and for this reason it has quite a popularity in large cities in spite of its other numerous defects. The business portion of London submits to its streets being torn up every four to seven years to relay the worn out wood pavements in order to get rid of the roar that stone pavements would cause. Macadam and telford are also noiseless, but the excessive annoyance from dust and mud and the constant repairs render them too objectionable in large cities. Brick pavements cause only a moderate amount of noise that is rarely objectionable, and it is free from the sharp click of the horses' hoofs that is characteristic of asphalt. Stone blocks are very noisy, both from the click of the horses' hoofs and the rumble of the wagon tires, but the worst offender is the cobble stone pavement, over which a lone, empty cart causes a thunder that would warrant a board of health in condemning it as a public nuisance.

Ease of Repairs.

EASE OF REPAIRS.—The repairs to a pavement come under two categories—that due to natural wear and tear and that caused by the frequent tearing up of the street for laying pipes, conduits, etc. The life of all pavements would be very considerably prolonged if they were not disturbed after once being properly laid. For when a pavement is torn up for pipe

laying, etc., the foundation is rarely replaced in proper condition, so that through subsequent settling the surface of the pavement is more or less severely thrown out of line. This causes excessive wear and injury to the pavement, especially as the defect is rarely remedied until it has become very bad. The time is not far distant when our large cities will no longer tolerate this frequent abuse of the pavements and temporary disuse of the street, as tunnels will be insisted on for carrying the pipes, wires, conduits, etc., in which alterations, repairs, etc., can be made without disturbing the pavement.

While stone pavements are the easiest to repair, they are closely followed by brick, and the most troublesome is asphalt.

Sanitary Value.

SANITARY VALUE.—A jointless pavement presents the smoothest surface to prevent the lodgement of filth and to enable rains or flushing to thoroughly cleanse it. Asphalt is, therefore, the most sanitary pavement, while stone blocks and cobble stones are the worst. A wood pavement, if made from closely fitting rectangular blocks, is excellent at first, but it soon wears into ruts and holes, in which the filth finds lodgement and later, as the wooden blocks decay, they give off unpleasant odors. Brick makes a good, sanitary pavement, especially if the small joints are grouted with cement, which latter is now the standard practice. The very remarkable record made by the U. S. Engineer Corps at Panama, which, from being the most unhealthy city in the world, with a frightful mortality from yellow fever, has been changed to a healthy city, has been largely attributed to vitrified brick. For not only have the streets been paved with brick, but also the sewers, so that between flushing by rains and with hose, a state of cleanliness has resulted that has tremenduously lowered the death rate and nearly made the hospitals useless.

SIZE OF BRICK.—When the manufacture of vitrified brick for paving first became an established industry, the brickmakers patterned their work after granite blocks. They soon found that it was very difficult to insure thoroughness and uniformity in burning such large sizes, especially as the blunder was made, and to some extent is still perpetrated, of giving them an appearance of thorough vitrification by salt-glazing, and many brick pavements were justly condemned for the failure due to the soft brick that resulted. Against the protest of engineers, many manufacturers changed to the size of building brick, and the marked improvement in quality and uniformity speaks for their good judgment, and has converted most engineers who have had much experience with paving brick. Today there are two sizes in the market, or standard and block. The standard size is about 8¼x4x2½ inches, or the same as building brick, while the block size is about 9x4x3 inches. Each size has its advocates, but the best records have been made in the pavement by the standard size.

Blocks.

Common Size.

Formerly brick were made with square or but slightly rounded edges and corners, but the sharp corner soon chips off under wear, and until so chipped it makes a poor footing for the horses, on account of the tightness of the joints. Brick are now made with rounded corners, using a radius of one-quarter to three-eighths inch, which makes a more durable brick and furnishes a much better footing.

Rounded Corners.

Some of the blocks on the market are patented, the patent being based on various shaped grooves and lugs pressed into their flat sides to assist in holding the tar or other filler, and of these the Hallwood patent is one of the best known, which is made by several concerns on a royalty. The grooves and lugs are not found necessary if the brick are laid on a good foundation, and their value is greater as a trade-mark than for their intrinsic merit for paving purposes.

Grooves and Lugs.

Concrete the Standard.

FOUNDATIONS.—The success of any pavement depends primarily on a good foundation, and brick must have a good foundation if a smooth, durable pavement is desired. In the early experience of our brick pavements, the enthusiasm of the brick advocates went so far as to claim that brick would be satisfactory on any kind of a foundation, and very poor supports, such as sand, plank, etc., were put under some of the early pavements, with the disappointing results that were bound to follow. Engineers have been quick to see this and insist on a good foundation, so that a concrete base is now the standard foundation. The concrete is made eight inches thick for heavy traffic, six inches for moderate, and four inches for very light traffic. Where the travel will not bear the expense of concrete, broken stone, gravel, or cinders have been substituted, thereby saving the expense of the cement and mixing. A still cheaper foundation that has been largely used in the small cities and towns is to use a four to six-inch bed of sand, on which is laid a course of No. 2 pavers placed flatwise.

Sand Cushion.

Whether the foundation be concrete, gravel or brick, a cushion of sand is always used between it and the top course of brick, to take up the unevenness of the surface of the foundation and any irregularities in the brick. This sand cushion is usually two inches thick, but the writer thinks it should be reduced to one inch, as this is sufficient if the foundation is leveled up with care, and the thinner the cushion the less the risk of the brick settling or getting displaced in service. The top course of brick are laid on edge at right angles to the street, and at 45 degrees at intersections, and the joints between the brick are filled with cement grouting, tar, pitch or sand. A cement filling, if of Portland cement, binds the brick into a monolith, and gives the best results, as it is not affected by hot weather. Tar or pitch is also a good binder and filler,

Fillers.

but it softens in hot weather, though this enables broken joints to reunite, which is not the case with cement. In either case the grouting or tar should be thin when applied, so that it can penetrate into the joints, which are usually only one-sixteenth to one-eight inch wide. Sand filling is much cheaper, and permits the easy removal of the brick for pipe laying, etc., and when once well worked in makes a solid pavement; but too frequently it is improperly applied by not having it perfectly dry and clean, when very little of it works into the cracks, no matter how persistently it is swept* over the surface. Before the filling is applied, the bricks are carefully rolled to a true, uniform surface with a heavy roller, after which any broken or chipped brick are replaced, and after the pavement is finally thrown open to traffic a half-inch layer of sand is left on top for a month or so, to insure thorough filling of the joints.

Drumming.

DRUMMING.—When brick are laid in cool weather and a cement filler is employed, there is frequently a hollow, drumming sound in the hot weather when a horse trots over it. This is due to the heat expanding the brick so that the pavement slightly arches or bridges between the curbstones and raises off from the sand cushion to a moderate extent. When cool weather returns the brick contract, the arching ceases and the noise disappears. To avoid this trouble, a wide joint should be left at or near and parallel with the gutter line that is filled with tar or asphalt. As the latter softens and yields in hot weather, it prevents the pavement from arching or rising off of the sand cushion.

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*Unless the sand is perfectly dry, it is better to flush it in with water, rather than attempt to work it in with a broom by sweeping.

Life of Brick Pavements.

LIFE OF BRICK PAVEMENTS.—As about forty years have elapsed since the first brick pavement was laid in Charleston, W. Va., and it is some twenty years since they have been extensively used, there is now considerable data on which to base an opinion as to the usual life of vitrified brick. There were naturally a good many poor brick turned out in the early pioneer days of the industry before the details for the successful manufacture of vitrified brick were understood and before it was realized that comparatively few clays or shales are suitable for a high grade brick. Quite a number of the early brick pavements have, therefore, been renewed and also some more recent ones that were laid when there was such a boom that some contractors would take anything that came from a factory with a paving brick tag. Since a standard method of testing has been adopted and with the elimination of factories that did not have suitable clays or equipment, a much better grade of brick has been put on the market. Comparing the grade of brick on the market today by the rattler test with those that lasted ten to twenty-five years in actual use, it is safe to say that the vitrified brick that can make a fair rattler test should last from twelve to twenty-five years under moderate business traffic, and for fifteen to thirty years when high grade. This is based on the brick having a good foundation and being properly laid—a matter that is now well understood and usually insisted on by municipal engineers. Extra good brick will have a naturally longer life than the above, while the heavy traffic of the downtown streets in a large city will more or less shorten the life.

The block on LaSalle street, Chicago, opposite the County Court House, was laid with Purington brick (standard size) about fifteen years ago. Although the pavement has been torn up with exceptional frequency and it has been subjected

to about the heaviest traffic of Chicago, it is still in fair condition and should last several years longer.

The first brick pavement laid in the United States at Charleston, W. Va., lasted thirty-five years, and while it is not a large city (12,000), the brick were made from a surface clay and were really a very hard burned building brick.

DETAILED COST OF BRICK PAVEMENT.

Detailed Cost of Brick Pavement.

While the cost of brick pavements will vary more or less in different places and also in the same place at different times, according to the changes in local markets, conditions, etc., the following generalized estimate from Baker's "Roads and Pavements," page 521, will give an idea as to how the cost is distributed. This is based on municipal work as performed by contractors:

	Cost per sq. yd.
Sub-grade rolling	$0.002
Concrete, 6 inches, materials	0.40
Labor of laying	0.07
Sand cushion, 2 inches sand at 90c per cu. yd	0.05
Labor of spreading	0.005
Brick blocks, 4-in. deep; cost f. o. b. cars destination	0.60
Hauling to street	0.04
Setting	0.03
Rolling	0.003
Turning and removing	0.01
Portland cement grout, 1 to 1 mixture	0.10
Expansion joint, tar, 1 gal. to 5 square yards	0.015
Total	$1.33

This cost of $1.33 per square yard does not include administration, wear and tear of tools, nor contractor's profit, which will usually bring the contractor's price up to $1.50 to $1.60 per square yard.

PAVING STATISTICS.

Paving Statistics.

To show the relative popularity of the different pavements in the year 1900 in 129 cities of the United States that had a population of 30,000 or more, the following figures, collected by the U. S. Department of Labor and published in their bulletin No. 24 (September, 1900), is quite interesting:

Asphalt	36,585,322 sq. yds. at	$2.75=	$100,609,635
Brick	21,648,768 sq. yds. at	1.75=	37,885,344
Cobble stone	21,600,245 sq. yds. at	.80=	17,280,196
Granite block	30,816,521 sq. yds. at	3.50=	107,857,823
Gravel	38,645,022 sq. yds. at	.20=	7,729,004
Macadam	82,680,545 sq. yds. at	.75=	62,010,409
Wood blocks	27,727,572 sq. yds. at	1.25=	34,659,465
Other kinds	9,553,000 sq. yds. at	2.50=	23,882,500
	8,888,200 sq. yds. at	1.00=	8,888,200
Total	278,145,195 sq. yds. costing		$400,812,576

The values in the above table have been estimated by Prof. Baker,* and while only approximate, it illustrates the magnitude of the investment in the larger towns and cities.

Of the large cities that use brick extensively, Philadelphia, St. Louis and Chicago have been in the lead, and the following table not only brings out the increasing growth in the use of brick, but also the decline in the use of wood and cobble stone pavements when the three periods of 1890, 1900 and 1906 are compared:

*Page 293, Baker's Roads and Pavements.

MILEAGE OF PAVEMENTS IN LEADING CITIES

Kind of Pavement:	Philadelphia			Chicago			St. Louis		
	1890	1900	1906	1890	1900	1906	1890	1900	1906
Asphalt	43.40	254.10	379.69	9.24	78.60	271.43	3.95	11.81	53.74
Stone Blocks	119.60	352.20	378.60	23.10	29.77	48.47	42.46	50.36	70.00
Cobble	375.10	69.20	61.40	......	....	......	......	......	......
Rubble	115.40	43.30	.....	.....	.....	.....	.....	......	......
Brick	19.80	119.50	145.71	......	29.51	87.41	......	14.23	133.49
Macadam	88.80	193 50	273 34	227.01	363.40	490 54	290.06	351.92	276.83
Bitulithic	.....	......	.....	......	.....	......	......	......	29.83
Granolithic	.....	12.80	12.77	......	......	.....	......	.....	......
Slag Block	......	5 60	9.82	......	......	......	......	......	......
Wood	.....	.....	......	410.29	763.21	581.18	5.76	6.89	2.84
Miscellaneous	....	......	.....	......	4.88	6 54	.....	.....	......
Totals	762.21	1050.20	1261.33	669.64	1269.37	1485.57	341.75	435.21	566 73

SPECIFICATIONS FOR BRICK PAVING.

Specifications.

To illustrate the type of contracts that are drawn up for brick paving, the following example is given from the St. Louis street department, which is the form on which contractors make up their bids in bidding for street work, which is let after advertising, to the lowest bidder. It will be noted that it calls for a cross-breaking strength of over 2,000 pounds per square inch and an absorption not greater than 2.0 per cent if the rattler loss is not over 25 per cent. When the rattler loss is less than 20 per cent, then an absorption as great as 4.0 per cent is allowed.

The St. Louis street department has always been partial to the cross-breaking test for bringing out the uniformity and care exercised in making the brick, which quickly shows up in this test. The 2 per cent absorption prejudice is a survival of the former idea that most engineers had that no paving brick could be relied on to withstand frost action if it absorbed over 2 per cent, although extra tough brick that suffer a loss of less than 20 per cent are conceded to be safe if the absorption is as high as 4.0 per cent:

CLASS "BC" CONTRACT AND SPECIFICATIONS FOR VITRIFIED BRICK STREET CONSTRUCTION, GRANITE CURB.

AGREEMENT, Made and Entered into this.............. day of.......................A. D. 190...., by and between .... part.... of the first part, and the "City of St. Louis," party of the second part, witnesseth:

Whereas, The Board of Public Improvements of the said City of St. Louis under the provisions of Ordinance No....... approved.....................and by virtue of the authority vested in the said Board by the charter and the general or-

dinances of the City did let unto the said part.... of the first part the work of improving..............................
by grading and preparing the roadbed for the superstructure, furnishing granite curbing and setting the same in Portland cement concrete; laying a roadway pavement to consist of a base of Portland cement concrete, and a wearing surface composed of the best quality of vitrified paving brick; making all proper connections and intersections with other streets and alleys, and guaranteeing to keep in repair all of the aforesaid work and materials for a term of five years, commencing on the date of acceptance of the work of improvement, as specified by the above mentioned ordinance.

NOW, THEREFORE, In consideration of the payments and covenants hereinafter mentioned, to be made and performed by said second party, the said first part hereby covenant and agree to do the work above mentioned in a substantial and workmanlike manner, in conformity with the plans of such work on file in the offices of the Board of Public Improvements and the Street Commissioner of the City of St. Louis and in accordance with the following:

SPECIFICATIONS.

GRADING AND PREPARING THE ROADBED FOR THE SUPERSTRUCTURE.

Grading and Preparing Roadbed.

The grading and preparing the roadbed for the superstructure will include all excavating or filling necessary to bring the sub-grade to a surface which will conform to and be parallel with the grade of the finished pavement and the sloping of intersecting streets or alleys. Any trees or stumps on or near the work will be grubbed without extra charge. All surplus earth or macadam shall be hauled to such city property within a distance of 2,000 feet as the Street Commissioner may designate and spread according to his directions; but if

no such place is designated, the material shall belong to the contractor and removed from the work by him. Where the embankment is in excess additional material for filling shall be furnished by the contractor.

Embankments must be spread in layers not exceeding one foot in depth and shall consist of clean, dry earth, stone, sand, gravel or other similar material. No refuse, vegetable matter or debris of any kind will be permitted in the fill. No allowance will be made for settlement or shrinkage, and payment will be made only on quantities, as shown by cross-sections, for excavation or embankment, which ever is in excess.

The roadbed shall, wherever practicable, be thoroughly rolled and compacted with a roller, weighing not less than eight tons, or a roller that will give a compression of three hundred pounds for each inch width of roller. All places that can not be reached by a roller shall be rammed with hand rammers, weighing not less than ninety pounds. If depressions appear, or if in the opinion of the Street Commissioner any of the material in the sub-grade is spongy or otherwise unfit to be used, he may order the same removed and the excavation refilled with stone, sand, gravel or other satisfactory material. After this refilling the roadbed shall be re-rolled until it is brought to a true, even and compact surface. The price bid per cubic yard for grading and preparing the roadbed for the superstructure, will include all work above mentioned necessary to bring the sub-grade to the proper shape and elevation, except the removal of unsuitable material below the sub-grade, which will be paid for both ways at the price bid for grading.

INTERSECTION WITH STREETS AND ALLEYS.

Intersections.

Wherever the work joins unimproved or macadamized streets and alleys, and the Street Commissioner deems it

necessary, it shall be protected by macadam spread behind the marginal curb hereinafter described. Where the work joins a paved street or alley, all old paving damaged during the construction work shall be carefully replaced by the contractor at his own expense to the satisfaction of the Street Commissioner; provided, however, that if said street or alley is under a maintenance contract, the contractor having said maintenance in his charge shall be permitted to make the repairs required and be paid for them in accordance with the terms of his contract, at the sole expense of the party of the first part under this contract.

CEMENT.

All cement to be used on the work herein specified shall be of the best quality of Portland cement, delivered in suitable packages with the name of the manufacturer plainly marked thereon. **Cement.**

It shall be subject to inspection and samples furnished for the following tests at any time:

1. Specific Gravity: When thoroughly dried at 100 degrees C. the specific gravity shall be not less than 3.10.

2. Fineness: It shall have by weight a residue of not more than 8 per cent on a No. 100 sieve and not more than 25 per cent on a No. 200 sieve.

3. Time of Setting: It shall not develop initial set in less than forty-five minutes nor final set in less than one and one-half hours nor more than ten hours.

4. Tensile Strength: Briquettes one square inch in section made of neat cement must develop tensile strength as follows: one day in air and six days in water 500 pounds, one day in air and twenty-seven days in water 650 pounds; when mixed with three parts of sand by weight: one day in air and

six days in water 250 pounds, one day in air and twenty-seven days in water 325 pounds.

The twenty-eight day test must show an increase of at least 15 per cent over the seven day test in the mortar briquettes.

Cement passing the requirements of the seven day test may be used at once, or held for the twenty-eight day result, at the option of the Street Commissioner.

5. Soundness: Two pats of neat cement shall be made about three inches in diameter and one-half inch thick at the center, tapering to a thin edge. These pats will be kept moist until finally set, when one will be placed in fresh water for seven days and the other in water which will be raised to the boiling point for six hours then allowed to cool. Neither of the pats must show distortion or cracks.

6. Sulphuric Acid and Magnesia: The cement shall not contain more than 1.75 per cent anhydrous sulphuric acid (SO_3) and not more than 4 per cent magnesia (MgO).

SAND OR LIMESTONE SCREENINGS.

If sand is used in the mortar for concrete it shall be clean, coarse, screened Mississippi River or Meramec River channel sand, and if limestone screenings are used, they shall pass through a sieve having sixteen meshes to the square inch and shall be free from all dirt and rubbish.

BROKEN STONE OR WASHED GRAVEL.

The broken stone or washed gravel used in the concrete shall be any hard rock satisfactory to the Street Commissioner and of such a size that it will pass through a two and one-half inch ring and be retained by a one-half inch ring. When delivered on the work it shall be deposited on a hard, clean surface and if such a surface is not available, it shall be deposited and kept on plank until used.

CONCRETE.

Concrete shall be mixed in the following manner and proportions by volume: Concrete.

One part of cement and four parts of sand shall be thoroughly mixed dry, after which a sufficient quantity of water shall be added to produce a mortar of the proper consistency. To this mortar will be added seven parts of wet broken stone or washed gravel and the whole thoroughly mixed in any manner satisfactory to the Street Commissioner.

The concrete thus prepared will be immediately spread on the sub-grade and rammed and compacted so as to produce a uniformly dense mass six inches thick.

No walking or driving over concrete in place must be permitted while it is setting, and it shall be allowed to set for at least five days and such additional length of time as may be directed by the Street Commissioner, before the pavement is put upon it.

Before placing fresh concrete against that which is already set, the old concrete must be thoroughly cleaned and wet so that the new work may readily form a bond with the old.

CURBING.

All curbing shall be of the best quality of granite, equal in material and finish to the sample in the Street Commissioner's office and the stones shall be not less than sixteen inches deep, six inches thick and four feet long. The bottom bed shall be roughly squared. The top and face shall have a rough pean hammer finish, the face dressed to the full depth of the stone and shall in no place vary more than three-eighths of an inch from a true plane. The back of the stone shall be dressed parallel to the face a depth of four inches below the top. Special care must be taken to cut the joints square with the Curbing.

face and top, and the joints shall be close for the full thickness and depth of the stone.

It shall be brought and kept to proper line and grade by using not more than two stone props, not to exceed ten inches in width for each piece of curb. It shall rest on concrete of the quality hereinbefore specified, six inches deep and twelve inches wide, and shall be backed with concrete six inches wide and ten inches deep or to a line six inches below the top of the curb. After the curb is set, the concrete shall be carefully forced and rammed below and behind the curb until it fully rests upon and is backed with concrete, as above described.

Care must be taken not to disturb or break the sidewalk pavement more than necessary, and in all cases, unless otherwise directed, it shall, when broken, be fully restored at the expense of the contractor.

Wherever in connecting with sewer inlets or old curbing, the joints are found to be too wide, they shall be filled with mortar consisting of one part of Portland cement and two parts of sand, at the contractor's expense.

No curbing will be set until the rough grading has been done and the concreting must be done in advance of the street concreting.

The price bid per lineal foot for granite curb, shall include the curb set complete.

MARGINAL CURB.

At all places where the pavement ends and where it is not protected by the granite curbing, a marginal curb shall be placed if the Street Commissioner so directs. This curb shall be made of oak plank two inches thick and twelve inches wide and shall be set on six inches of concrete, projecting five inches on each side of the curb and shall have concrete

five inches wide on both sides to within eight inches of the top of the pavement.

The price bid for marginal curb per lineal foot will include the curb set complete together with the excavation outside the face.

VITRIFIED BRICK WEARING SURFACE.

Upon the foundation shall be spread about one inch of coarse screened sand, upon which shall be laid, as hereinafter specified, the vitrified paving brick. **Wearing Surface.**

The bricks shall not be less than eight inches nor more than ten inches long, not less than two and one-half inches nor more than three and one-half inches wide, not less than four inches nor more than four and one-half inches deep, and shall have rounded edges with a maximum radius of one-quarter of an inch. They shall be free from lime or other impurities that will injuriously affect them when immersed in water, uniform in size and quality, thoroughly burned and annealed, and free from internal flaws, cracks and laminations. All bricks so distorted in burning or with such prominent kiln marks as to produce an uneven pavement, will be rejected. Not less than one hundred bricks of the kind proposed to be used shall be submitted as samples, and shall pass the following tests:

1. They shall show a modulus of rupture in cross-breaking of not less than two thousand pounds per square inch.

2. Specimen bricks shall be placed in the machine known as a "Rattler" twenty-eight inches in diameter and making thirty revolutions per minute. The number of revolutions for a standard test shall be eighteen hundred, and if the loss of weight by abrasion exceeds 25 per cent of the original weight of the bricks, then they shall be rejected. An official test shall be the average of two of the above tests.

3. They shall not absorb more than 2 per cent of their own weight of water after being immersed in water for forty-eight hours; provided, however, that an absorption of not exceeding 4 per cent may be allowed, in case the brick will show a loss of weight by abrasion of not over 20 per cent of the original weight of the brick. The absorption test shall be made on bricks that have been broken and passed through the "Rattler."

After the surface of the sand has been made smooth, exactly parallel to the desired surface of the street after completion, and uniformly dense, the bricks shall be laid upon it. They shall be set on edge, in straight courses, as closely and compactly as possible and at right angles to the line of the work, except at street intersections, where they are to be laid as the Street Commissioner shall direct. All joints shall be broken by a lap of at least two inches, and no bats or broken bricks will be allowed, except at the ends of the work, for the purpose of breaking joints or making closures, and in no case shall a bat less than three inches long be used.

After the bricks are laid they shall be surfaced and bedded by a thorough rolling with a steam roller, weighing not less than three nor more than six tons, and the pavement shall, when completed, conform accurately to the grade and cross section of the roadway. Wherever a roller can not be used, the pavement shall be rammed with a paver's rammer, weighing not less than seventy-five pounds. If after rolling or ramming, any bricks are found to be slightly above or below the surface of the pavement, they shall be carefully adjusted, so that when the grout, hereinafter described, is put in place, there will be no unevenness in the pavement. An expansion joint one inch wide shall be placed on each side of the roadway against the curb or outer edge of the gutter. This joint shall be about four inches deep and shall be filled with pitch

heated to a temperature of three hundred degrees Fahrenheit, to within one-half inch of the surface of the pavement. The grout shall consist of one part of Portland cement and one part of sand mixed with enough water to make it sufficiently fluid, when properly stirred, to completely fill the joints in the pavement. The cement and sand shall be thoroughly mixed dry until no streakiness remains in the mixture and in such quantities as may be desired. Not more than two ordinary water buckets full of this dry mixture shall be wet at one time. From the time water is added to the cement and sand until the grout is deposited on the street, the mixture shall be constantly stirred in order to prevent a separation of the sand and cement. As soon as the grout is transferred to the pavement, it shall be rapidly swept into the joints and the grouting shall not be considered as completed until the joints are completely filled. After the grout has been poured and before it has set, the contractor shall carefully inspect the surface of the pavement and correct any irregularities that have not been previously discovered, whereupon a thin layer of clean, coarse sand shall be spread over the pavement. The newly finished work shall then be protected by substantial barricades, and if deemed necessary, by watchmen to guard the barricades for a period of seven days after the grout is applied.

GUARANTEE.

The said............................part.... of the first part hereby expressly guarantee................to maintain in good order, the grade and surface of all the aforesaid work of improvement and the materials used in connection therewith, for a term of five years throughout, commencing on the date of acceptance of the work, and bind .... heirs, executors, administrators, successors or assigns to make

Guarantee.

all repairs, which may from any imperfections in said work or materials, or from any rotting, crumbling or disintegration of the materials, become necessary within that time, or if the surface of the pavement shall have any cracks, bunches, holes or depressions that shall measure more than one-half inch from the under side of a straight edge four feet long, laid on the surface, the part.. of the first part shall, whenever notified by the Street Commissioner that repairs are required, at once make such repairs at............own expense. And if they are not made within five days after written notice is given by the Street Commissioner, then he shall have the right to cause such repairs to be made and the cost thereof may be recovered by the city upon the bond given to secure the faithful performance of the contract let hereunder, by appropriate action in any court of competent jurisdiction.

And it is further agreed in addition to the above that if during the first year of the term of guarantee, repairs are not made as directed, after written notice is given by the Street Commissioner, then he shall have the right to cause such repairs to be made and the whole cost thereof shall be paid out of the special fund of $200.00, which the part.... of the first part ha.... paid into the treasury before executing this contract, in accordance with Section 1991 of "The Revised Code of St. Louis." And this special fund shall be kept up to the full amount of Two Hundred Dollars, which amount will be finally repaid in the manner set forth in Sections 1992 and 1993 of "The Revised Code of St. Louis."

At the end of the five year period, the Street Commissioner will determine whether or not the foundation is sound and the entire wearing surface of the roadway is in a reasonably smooth condition and is free from signs of disintegration. The principal and........................securities under

this contract shall not be discharged from liability on their bond hereunder, until the Street Commissioner shall so determine and certify thereto in writing to the principal under this contract. And it is further expressly agreed, that if at any time during the term for which the contract for guarantee is in force, the pavement or any part thereof does not meet the requirements above specified, then the Street Commissioner may, with the approval of the Board of Public Improvements and of the Mayor, so notify the contractor, and the contractor shall within three months after receiving such notice, totally repair or reconstruct the whole or such part of the pavement, as does not meet the requirements, with the same kind of material as heretofore applied, or with some other material approved by the Board of Public Improvements. And if the contractor fails to so totally repair or reconstruct the pavement within three months after having been notified, the Board of Public Improvements may, with the approval of the Mayor, cancel the contract without thereby discharging the liability of the contractor and sureties, and relet the work of such total repairing or reconstructing and the cost thereof shall be paid by the city and the amount collected by suit from the contractor and the sureties. And it is further agreed that whenever any repairs of the pavement are made necessary from the construction of sewers, the laying of pipes, or telegraph wires, or from any other disturbance of the same, by parties acting under permits issued by the city, the contractor shall, on notification from the Street Commissioner, in all cases (except where the party causing the disturbance is required to restore the pavement), at once make all necessary repairs in conformity with the specifications under which the pavement was constructed. The cost of all such repairs, when done by the contractor, exclusive of trenching and back-

filling, which shall be done by the parties who hold the permits, and in the same manner as now required by existing ordinances, shall be paid for at the rate of Three Dollars ($3.00) per square yard, provided, however, that no single cut will be repaired for less than Ten Dollars ($10.00), and the measurements thereof, together with the amount due the contractor therefor, shall be certified to by the Street Commissioner, and shall be paid out of the fund "Street Repairs—Reconstructed Streets," and the amount shall be certified by the Street Commissioner to the Auditor, who shall reimburse by transfer the aforesaid fund from the funds of the proper department, if the repairs were made necessary by the construction of any public improvement; and out of the funds to be deposited by persons taking permits for opening the street before such permits were granted, if the repairs were made necessary by work done thereunder. And it is agreed that the contractor shall have the right to make all repairs (except where the party causing the disturbance is required to restore the pavement), which become necessary by the construction of any public improvements or work done by private parties under permits issued and granted by the city on the basis of compensation aforesaid; provided, however, that it is furthermore covenanted and agreed that this contract shall not be affected, impaired or avoided, and that no claim or compensation for damages shall be presented by or allowed the contractor for or on account of a disturbance or tearing up of the street by the City of St. Louis or by any contractor by it employed, or by the grantee of any franchise now or hereafter given and granted by the city for laying conduits, street railway tracks, gas pipe or wires of any character upon, in or under said street.

GENERAL STIPULATIONS.

General Stipulations.

IT IS FURTHER EXPRESSLY AGREED, between the parties hereto that this contract is made subject to the conditions and sipulations which follow:

1. The first party shall not assign or transfer this contract or sub-let any of the work embraced in it.

2. The first party shall commence the work at such points as the Street Commissioner may direct, and conform to his directions as to the order of time in which the different parts of the work shall be done, as well as to all his instructions as to the workmanship, character of the work and quality of the materials.

It being expressly understood that the work is to be prosecuted in sections of not less than the space between any two intersecting streets and that the provisions of stipulation 10, relative to hauling, inspection, removal and piling of material shall apply to the work on each of said sections on the whole line of the work.

3. Any work not herein specified, which may be fairly implied as included in this contract, of which the Street Commissioner shall judge, shall be done by the first party without extra charge.

4. The first party upon being so directed by the Street Commissioner, shall remove or reconstruct, or make good at his own cost, any work which the latter shall decide to be defectively executed; and any omission to condemn any work at the time of its construction shall not be construed as an acceptance of any defective work, but the first party will be required to correct any imperfect work whenever discovered before final acceptance of the work.

5. The first party will be required to observe all city ordinances in relation to obstructing streets, maintaining sig-

nals, keeping open passage ways and protecting the same where exposed, and generally to obey all laws and ordinances controlling or limiting those engaged on the work, and the said first party, contractor, hereby expressly binds himself to indemnify and save harmless the City of St. Louis from all suits or actions of every name and description, brought against the said city for or on account of any injuries or damages received or sustained by any party or parties by or from the acts of said contractor, or his servants or agents in doing the work herein contracted for, or by or in consequence of any negligence in guarding the same, or in any improper materials used in its construction, or by or on account of any act or omission of the said contractor, or his servants or agents.

6. To prevent all disputes or litigation, it is further agreed by the parties hereto, that the Street Commissioner shall in all cases determine the amount or quality of the several kinds of the work which are to be paid for under this contract, and he shall decide all questions which may arise relative to the execution of this contract on the part of the contractor, and his estimates and decisions shall be final and conclusive.

7. This contract is entered into subject to the approval or rejection of the council, and subject to the City Charter, and ordinances in general, and in particular to the following provisions of Article 6, Section 28, of said Charter, and of Sections 1921 to 1932, all inclusive of "The Revised Code of St. Louis," all of which by this reference are made parts hereof, as if here fully set forth:

a. The aggregate payments under this contract shall be limited by the appropriation contained in Ordinance No...... authorizing the work to be done.

b. "On ten days' notice, the work under said contract may, without cost to or claim against the City of St. Louis, be suspended by the Board of Public Improvements, with the ap-

proval of the Mayor, for want of means or other substantial cause."

8. The Street Commissioner shall have the right to make alterations in the line, grade, plan, form or dimensions of the work herein contemplated, either before or after the commencement of the work. If such alterations diminish the quantity of work to be done, they shall not constitute a claim for damages or for anticipated profits on the work dispensed with; if they increase the amount of work, such increase shall be paid for according to the quantity done, and at the price or prices stipulated for such work in this contract.

9. The first party shall not be entitled to any claim for damages for any hindrance or delay from any cause whatever, in the progress of the work, or any portion thereof; but such hindrance may entitle said first party to an extension of the time for completing this contract sufficient to compensate for the detention, the same to be determined by the Street Commissioner, provided he shall have immediate notice in writing of the cause of detention.

And it is expressly understood that the city or any corporation or individual holding franchises under it may enter upon the work during its progress and adjust their tracks, poles, manhole covers, inlets, etc., so as to meet the new conditions caused by the work.

10. The work embraced in this contract shall be begun within one week after written notice to do so shall have been given to the contractor by the Street Commissioner, and carried on regularly and uninterruptedly thereafter (unless the said Commissioner shall otherwise, in writing, specially direct), with such a force as to insure its full completion within........................thereafter, unless the time shall have been extended by the Street Commissioner as aforesaid

and then within said period of............plus the additional time allowed by said Commissioner the time of beginning, rate of progress and time of completion being essential conditions of this contract. And if the contractor shall fail to complete the work by the time above specified, the sum of five dollars per day for the first ten days and the sum of ten dollars per day for each and every day thereafter until such completion, shall be deducted from the moneys payable under this contract.

All materials to be used in the work before they are laid will be carefully inspected and all rejected material shall be immediately removed by the contractor from the work. The contractor will be required to pile his material, so that it will not be within three feet of any fire hydrant, and if any of it is placed upon the sidewalk sufficient passageway must be provided and also free access from the roadway to each house on the line of the street.

The contractor shall furnish and shall have on the line of the work a complete and sufficient plant of tools, rollers, carts, etc., so as to carry on the work expeditiously and in a workmanlike manner.

The contractor will be required to furnish such laborers as may be necessary to aid the inspector in the examination and culling of material.

11. And if the contractor shall assign this contract or abandon the work, or shall neglect or refuse to comply with the specifications or stipulations herein contained, or if at any time the Street Commissioner shall be of the opinion that the work is unnecessarily delayed and will not be finished within the prescribed time, he shall notify the contractor in writing to that effect; and if the contractor shall not within five days thereafter take such measures as will, in the judgment of the said Commissioner, insure the satisfactory com-

pletion of the work, the Board of Public Improvements shall have the right, with the consent of the Mayor, to annul and cancel this contract and to relet the work, or any part thereof, and such annulment shall not entitle the contractor to any claim for damages on account thereof, nor shall it affect the right of the city to recover damages which may arise from such failure.

NOTE:—The word "contractor" wherever used in this instrument, means the first party to this agreement, or the legal representative of such party; and the words "Street Commissioner," refer to the person holding that office for the time being, and to his properly authorized agents, limited by the particular duties entrusted to them.

PAYMENTS.

Payments.

In consideration of the completion by the said first party of all the work embraced in this agreement in conformity with the specifications and stipulations herein contained, the party of the second part hereby agrees to pay to the said first party the following prices, by issuing special tax bills as hereinafter provided:

For grading and preparing the roadbed for the superstructure, per cubic yard..................................cents;

For granite curbing, furnished and set complete, per lineal foot..............................Dollars ($............);

For marginal curbing, furnished and set complete, per lineal foot... cents;

For vitrified brick pavement, including concrete foundation, furnished and laid complete, per square yard.. Dollars ($..........);

For macadam, per cubic yard............................ ....Dollars ($..........).

When all the work embraced in this contract is fully com-

pleted, in accordance with the specifications and stipulations of this agreement, without regard to the provisions of guarantee and accepted by the Street Commissioner, said Commissioner shall cause a careful measurement of said work to be made, and certify the same to the President of the Board of Public Improvements, who shall compute the cost thereof according to the terms and prices of this agreement and levy and assess the same as a special tax against each lot of ground chargeable therewith in the names of the owners thereof.

The lots of grounds chargeable aforesaid are those embraced within a district defined and bounded in Section 14 of Article 6 of the Charter of the City of St. Louis.

One-fourth of said cost shall be levied and assessed as a special tax upon all the property fronting upon or adjoining the improvement hereinbefore described, in the proportion that the frontage of each lot, so fronting or adjoining bears to the total aggregate of frontage of all lots or parcels of ground upon or adjoining the improvement, and the remaining three-fourths of the cost shall be levied and assessed as a special tax upon all the property in the area district defined and bounded in said Section 14 of Article 6, of the Charter of the City of St. Louis, in the proportion that the area of each lot or parcel of ground, or the part of such parcel of ground, lying within said district, bears to the total area of the district, exclusive of streets and alleys.................
....

Each of said special tax bills so to be issued shall be divided into...........equal parts, as provided by the ordinance authorizing said improvement, the first installment to become due and payable thirty days after due notice of the issuance thereof, without interest, and the remaining installments to become due and payable at intervals of one year

thereafter, provided, however, that the owner or any person interested in the property charged with any tax bill may pay the same in full at any time within thirty days after such notice without interest, and may pay the same in full at any time by paying interest thereon as follows:

If paid at or before maturity, and more than thirty days after notice as aforesaid, at the rate of 6 per cent per annum from date of notice to date of payment; if paid after maturity, at the rate of 6 per cent per annum from date of notice to date of maturity, and at the rate of 8 per cent per annum from date of maturity to date of payment. All interest to be payable annually from date of notice as aforesaid, and if any installment or equal part, or any interest on any installment be not paid when due, then at the option of the holder thereof all remaining installments shall become due and collectible with interest thereon as above provided. And said special tax bills shall be made out by the President of the Board of Public Improvements and by him registered in his office in full, and certified and delivered to the Comptroller and his receipt taken therefor, and by him registered and countersigned and delivered to the party of the first part, in whose favor they are issued for collection, and his receipt taken in full of all claims against the city on account of said work.

PROVIDED, That nothing herein contained shall be so construed to affect the right of the city, hereby reserved, to reject the whole or any portion of the work aforesaid, should the measurement or computation before mentioned be found or known to be improperly made, or to be inconsistent with the terms of this agreement.

The said ....

....as Principal and

.... and

as Securities, hereby bind themselves and their respective heirs, executors, administrators, successors or assigns, unto the said City of St. Louis in the penal sum of...Dollars, lawful money of the United States, conditioned that in the event of the said.......................................shall faithfully and properly perform the foregoing contract, not only as to the work of construction, but also as to the repair and guarantee thereof, according to all the terms thereof, and shall, from time to time, as soon as the work contemplated by said contract is completed, pay to the proper parties all amounts due for material and labor used and employed in the performance thereof, then this obligation to be void, otherwise in full force and effect. Said bond may be sued on at the instance of any material man, laboring man, or mechanic, in the name of the City of St. Louis, to the use of such material man, laboring man or mechanic, for any breach of the conditions hereof; provided, that no suit shall be instituted after the expiration of ninety days from the completion of any work under the above contract.

IN WITNESS WHEREOF, the said.....................
as principal and ....
and .... as securities, parties of the first part, have hereunto set their hands and seals respectively and the City of St. Louis, party of the second part, acting by and through the Board of Public Improvements aforesaid have subscribed these presents, the day and year first above written.

WITNESS:

....(Seal)
....(Seal)
....(Seal)

....(Seal)
....(Seal)
....(Seal)

The City of St. Louis, by............................

President Board of Public Improvements.

Countersigned:...............................

Comptroller.

CITY COUNSELOR'S OFFICE.

St. Louis,.........................190..

The foregoing Agreement and Bond are in due form according to law.

....

City Counselor.

MAYOR'S OFFICF.

St. Louis,..........................190..

I hereby approve of the securities to the foregoing Contract and Bond.

....

Mayor.

N. P. B. M. A. SPECIFICATIONS FOR LAYING PAVING BRICK.

Standard Specifications.

The following specifications for laying brick pavements is recommended by the National Paving Brick Manufacturers' Association. As this body represents the leading makers of paving brick throughout the United States, it is the result of a most broad and thorough experience in the use and abuse of vitrified brick pavements, and is worthy of careful consideration. It covers both the use of concrete and No. 2 brick for the foundation:

DIRECTIONS FOR LAYING BRICK STREET PAVEMENTS; SPECIFICATION ONE—BEST KNOWN CONSTRUCTION—CONCRETE BASE OR NO. 2 BLOCK PAVEMENT—CEMENT FILLER.

Grading.

SUBSTRUCTURE OR GRADING.—Earth in excavation to be removed with plow and scraper, or other device, to within two (2) inches of subgrade, then brought to the true grade with the roller, the weight of which should be not less than five (5) nor more than eight (8) tons. If the earth is too hard to receive compression through the roller, then loosen the remaining inches with a pick and cart away.

Earth in embankment must be applied in layers of eight (8) inches in thickness and each layer thoroughly rolled, and in both excavation and embankment the subgrade must have a uniform density.

If the underground is spouty clay, tile drainage should be provided to carry off this accumulation of wet.

REASONS WHY.—The attempt to remove the earth to the proper depth or grade line with plow and scraper is usually fatal to the general surface of the subgrade, for the reason that no man can hold a plow, or team draw the same to a straight grade, therefore, in an attempt to get too close to subgrade with a plow, holes will be gouged below the true grade. When the shovelers commence the removal of the plowed earth, they will invariably sink these same low places still lower, and when the finishing begins these low places will necessarily have to be filled and compacted with the roller. Then you have different characters of solidity, which are objectionable and detrimental to good work.

The prime reasons for not using a roller weighing more than eight (8) tons is that they are too cumbersome and unwieldly and very slow moving, while with a lighter and quicker

moving one you pass many times over the subgrade and get better results in having your subgrade more uniformly compacted.

The filling with loose earth of portions of the work that is below grade will be found necessary very often if an attempt is made to plow too close to the grade line, then the lighter roller is found more effective in bringing such places to the same density as the undisturbed portion.

When embankment is necessary to bring the street to the required grade line, it is very obvious that the earth should be deposited in equal layers of not more than eight (8) inches thick, and each layer thoroughly rolled. A six or eight ton, or even a heavier roller, will have little effect in compression below eight inches, and all embankments should be compacted as thoroughly as possible before applying the superstructure; for earth once disturbed and removed from its natural bed takes a long time to acquire its original solidity, the scientific reason for which would take too much space and time to enter upon here.

Under-drainage is not absolutely essential, but in wet and spouty under stratum much is added to the durability of the structure by keeping the sub-foundation dry, and under foregoing wet conditions under-drainage is the only way to accomplish the best results.

Curbing.

CURBING.—Stone curbing should all be hauled and distributed and set before the grading is finished, and may then be used as a guide to finish the subgrade.

It should range in thickness from four (4) to six (6) inches, twenty (20) to thirty-six (36) inches wide, the business and street traffic governing the same, and lengths not shorter than four (4) feet, except at closures. Neatly dressed on top with a square or rounded edge, and four (4) inches

down on the inside. The outer surface to be tool-dressed to the depth of the face exposed and to the depth of the thickness of the brick and sand cushion. If cement concrete curb is used, it should be completed before the work of finishing the sub-grade begins.

Curb corners of streets and alleys should be made circular.

EXTRA MENTION.—If concrete curb and gutter is used, it must be placed in position before any of the other work is commenced, except possibly, some of the heavier grading, and it is essential, if natural stone curb is used, to have it all in place before any portion of the grading is finished, for the reason that, after you have finished a subgrade and given it the proper contour and surface it should never be disturbed by unnecessary wheelage, and nothing destroys it so effectually as hauling heavy stone curb over it; and in renewing these broken places they are rarely returned to the original conditions.

The curb should all be set before the finishing of the subgrade begins, if for no other reason than that it affords the very best guide for the said finishing.

MARGINAL CURB.—Should always be of a hard and durable character of stone, and from fourteen (14) to eighteen (18) inches deep, dressed on top, and five (5) inches down on the face next to the brick. Set to accurately fit the curvature of the cross-section of the street on six (6) inches of concrete and backed up with the same within six (6) inches of the top.

EXTRA MENTION.—Marginal curb should always be of a hard and durable character of stone (hard wood is better than soft stone), and set on and backed up with a good Portland cement concrete, mixed in the proportion of one to two to four.

Marginal curb is as a rule used to sustain a paved street against one that is unpaved, therefore, the reason it should be well and properly set, and unless it is, the impact of the wheelage in passing from the unpaved to the paved street will soon drive it down and loosen it if not firmly and securely set, and in a short time the pavement begins to break and give way and will continue to do so for quite a distance into the intersection.

Even with the marginal curb set in the above manner there should be a margin of crushed stone or clean gravel to the width of three or four feet and eight (8) or ten (10) inches deep spanning the width of the opposing unpaved street and tamped firmly against the marginal curb. With these precautions you will avoid the rapid destruction of the margin of your paved streets.

Foundation.

FOUNDATION.—Note: It has been fully demonstrated, as shown by the report of Prof. Baker (a copy of which may be had upon application), that a foundation constructed of No. 2 Paving Block possesses greater strength than a six-inch concrete base. It affords the greatest possible sanitation and it is believed by many engineers that it affords a better foundation even than concrete. Other physical features afforded are favorable to the No. 2 Block foundation, as well as the fact that in many cases even a less cost price is secured by its use. Therefore, either the No. 2 Paving Block foundation may be adopted, or concrete foundation as may be desired.

NO. 2 PAVING BLOCK FOUNDATION.—Upon the subgrade as heretofore prepared shall be spread a base of sand two (2) inches in thickness and which shall be brought to a perfect grade conforming to that of the finished street.

There shall be laid flatwise at right angles with the street,

upon this grade thus prepared, a layer of No. 2 Paving Block not less than three (3) inches in thickness, the interstices of which shall be filled with a filler composed of two parts of clean sand and one part of Portland cement. This filler shall be prepared and applied as provided for in Section 10 of this direction and specification. The foundation thus made should remain undisturbed at least thirty-six (36) hours before the sand cushion herein provided for may be spread, and at least ten (10) days must elapse before rolling and compacting of brick surface is allowed, and in no event must teams be permitted or hauling be allowed upon this surface during this period.

CONCRETE FOUNDATION.—Should be of approved quality of hard rock, free from all refuse and foreign matter, with no fragment larger than will pass through a two (2) inch ring, and excluding all fragments less than one inch in their longest dimensions.

Clean, sharp, dry sand thoroughly mixed in its dry state with an approved brand of either hydraulic or Portland cement until the whole mass shows an even shade. If hydraulic, the proportion of mixture should be one part of cement and two parts of sand. If of Portland, one part of cement to three parts of sand.

To the above mixture should be added sufficient clean water to mix to a plastic mass, fluid enough to rapidly subside when attempted to heap into a cone shape. To this mixture add four (4) and six (6) parts, respectively of damp crushed stone, or good gravel carrying sufficient sand to make the mixture, and then turn the whole mass over not less than three (3) times, or until every fragment is thoroughly coated with the cement mixture. For the reception of this mixture, the grade should be set off in five-foot squares, with a stake

at each corner. Tops of each should be at the surface of concrete, which must be tamped until free mortar appears on the surface. Occasional sprinkling in extra hot, dry weather is beneficial. After thirty-six hours the cushion sand may be spread.

EXTRA MENTION.—If the combination of gravel and sand is used the mixture for natural cement should be one (1) measure of cement to six (6) measures of the mixture. If Portland cement, one (1) measure of cement to eight (8) measures of the mixture.

There is but one way to make good cement mixtures, presuming, of course, you have good material, and that is to thoroughly mix the dry materials. It is essential that the sand and cement should be thoroughly incorporated in their dry state, if not then it can't be done after the water is applied. In the first, you will have a homogeneous mass; in the second, a heterogeneous. In the one your mixture is complete and your structure is uniform; in the other, it varies and your structure is uncertain. The above applies especially to platform mixing. In machine manipulation the dry mixing isn't so readily obtainable, but could be more nearly approached if greater care were taken. Thorough mixing in both dry and wet state, with good material and proper proportions, insures a good concrete, whether it be of crushed stone or gravel.

Sand Cushion.

SAND CUSHION.—Sand should be clean and free from foreign or loamy matter. It need not necessarily be sharp. It should be two (2) inches thick before the compression of the brick by rolling. The sand should be spread by the aid of a template the whole or one-half the width of the street, and made to conform with the true curvature of the street cross-section.

EXTRA MENTION.—The preparation of the subgrade having been, with care, brought to a true plane as to curvature and grade, and to a uniform thickness, the work is ready for the cushion for the brick, for which any good, clean sand may be used whether it be sharp or spherical, but it is next to the impossible to spread it satisfactorily with a template or in any other manner when it is wet, and if you insist on your pavement maintaining its symmetrical form the sand must be evenly spread; and there is but one method for doing this, and that is mechanically, by the aid of a template, formed to fit the curvature of the street and armed with small metal wheels at either end, rolling on the curb at one end and on a 4x4-inch scantling laid lengthwise through the center of the street at the other.

If the roadway of the street isn't to exceed twenty-five (25) feet in the width or less, the template can be made to span the entire width, both ends rolling on the curb.

This manner insures an even thickness of sand over the surface of the concrete, giving to each individual brick a like thickness of cushion, so that when the brick surface is rolled each brick will present the same resistance to the pressure of the roller, and you will then perforce have a smooth surface, otherwise if the sand is of uneven thickness the tendency of those brick resting on the thicker bed of sand is to sink, under the pressure of the roller, lower than those resting on a thinner layer, and the result is an undulating and uneven surface.

Brick.

BRICK.—The brick should all be hauled and neatly piled within the curb line before the grading is finished, or if allowed by the engineer, delivered in wagons and carried from the pile or wagon on pallets with clamps—not wheeled with barrows. In hauling from car no throwing or dumping is allowed. They should be first-class and thoroughly vitrified,

showing at least one fairly straight face; if the edges are rounded the radius should not be greater than 3-16 of an inch. They should not be less than 2¼x4x8, or more than 3½x4x9½ inches, free from cracks, with but slight lamination, and at least one edge with but slight kiln marks allowed, and should stand the tests promulgated by the National Brick Makers' Association.

EXTRA MENTION.—It is not only good practice to have all of the brick hauled and distributed just inside the curb line before the work of grading begins on any street block, but it is economy, as experience has taught us that it is very expensive to attempt to get brick into a block after the other work has begun. Each side of the street should have the required number of brick neatly ricked up to lay to the center of the street, thereby always maintaining the minimum distance to carry the brick to the setter.

In order to get the brick to the setter with the least possible abrasion or injury to the same, it is best to carry them on pallets, and so deposit them that the person laying them in the street will deposit them perfect edge up. No wheeling or teaming should be permitted over the brick at any stage prior to opening the same to the public .

Brick Laying.

BRICK LAYING.—Brick may be laid either at a right angle or an angle of 45 degrees to the curb, as the engineer may direct, and in either way the line or course of brick must be kept straight or within a maximum variation of two inches; if greater than that, as many courses as necessary should be taken up and relaid until the defect in alignment is removed.

No parts of brick should be allowed in the pavement except the beginning or ending of courses or other closures. The brick must be laid with the best edges exposed as near in contact as possible; they must be closely inspected before

laying and also after laying and after rolling. All soft brick, and those badly spalled or ill-shapen, must be removed and replaced with perfect ones. The kiln-marked ones may be turned over, and if the reverse edge is smooth and no other faults be found, they can remain in the pavement.

EXTRA MENTION.—As to the alignment of the courses of the brick there is but little choice, either way is admissible without comment. The brick should be as nearly in contact as it is possible to lay them, for when the rolling is in progress, if there is appreciable space between the brick in the compression and bedding into the cushion sand, the brick will have a tendency to rock, and instead of receiving a flat foundation, as they should, it will be in a curved form, made by the rocking of the brick as the roller passes on and off them, and the pavement will require more grout to fill the interstices.

It isn't bad practice, if the gutter gradient is very flat, to lay five or six longitudinal courses parallel with the curb, as there will be less hindrance to the gutter drainage.

Rolling and Tamping.

ROLLING AND TAMPING.—After the brick in the pavement are inspected and the surface is swept clean of spalls, they must be well rolled with a five (5) ton steam roller in the following manner: The brick next the curb should be tamped with a hand wood tamper to the proper gutter grade. The rolling will then commence near the curb at a very slow pace and continue back and forth until the center of the pavement is reached, then pass to the opposite curb and repeat in the same manner to the center of the street. After this first passage of the roller the pace may be quickened and the rolling continued until each brick is firmly imbedded in the sand cushion. The roller shall then be started at the end of the block and the pavement rolled transversely at an angle

of 45 degrees to curb, repeat the rolling in like manner in the opposite direction. Before this transverse rolling takes place all broken or injured brick must be taken up and replaced with perfect ones.

EXTRA MENTION.—There is no question open to discussion as to the virtue of a steam roller on a brick pavement. It is very necessary in order to give it a smooth surface. The transverse rolling is very necessary in order to remove the slight wavy condition of the surface extending laterally from curb to curb, which will occur after the longitudinal rolling, and is the result of the thrust or impact occasioned by the propelling power of the roller. If the roller was drawn instead of being propelled these apparent waves would not occur. Therefore, the transverse rolling will practically remove them. The longitudinal rolling should always be from curb toward the center. The curved transverse section of the street has a tendency to move the brick endwise toward the curb, therefore, under the pressure of the roller, if you start the roller in the middle and roll toward the curb the gutter bricks that you have previously tamped to grade will be very much disturbed and your flow line will require retamping. If it were practicable to use the roller absolutely against the curb the rolling might be done from the center to the curb.

Expansion Cushion.

EXPANSION CUSHION.—An expansion cushion must be provided for next to the curb. It must be one inch or more in thickness, according to the width of the street. This cushion shall be composed of pitch or asphaltum composition, filling two-thirds the allotted space, the remaining top third to be filled with sand.

EXTRA MENTION.—This pitch joint next to and along the curb answers two purposes, it takes up the expansion of the brick and prevents a possible cracking of the pavement

through and along the center of the street, which sometimes occurs if the ends of the courses of the brick are abutted directly against the curb, which acts as a skewback or haunch to the arc of the pavement, which is often strong enough (especially if the sidewalk is up to and against the inside of the curb) to resist the force of expansion in that direction and it will find relief in raising the pavement and the cracking mentioned above may occur. And again, in taking up the expansion the brick are kept in contact with the sand cushion below, thereby preventing the rumbling noise so often heard, and occasioned wholly through lack of contact.

The inch of sand on the top of the pitch joint has a tendency to prevent the pitch from flowing, which it is likely to do in very hot weather. It is essential that the board occupying the place to be filled with pitch remain in place until after the street is in all other respects finished, but always withdrawn and the pitch applied within thirty-six hours after the application of the cement filler.

Filler.

THE FILLER.—The filler shall be composed of one part each of clean sand and Portland cement. The sand should be dry. The mixture, not exceeding one-third bushel of the sand, together with a like amount of cement, shall be placed in the box and mixed dry, until the mass assumes an even and unbroken shade. Then water shall be added, forming a liquid mixture of the consistency of thin cream.

From the time the water is applied until the last drop is removed and floated into the joints of the brick pavement, the same must be kept in constant motion.

The mixture shall be removed from the box to the street surface with a scoop shovel, all the while being stirred in the box as the same is being thus emptied. The box for this purpose shall be 3½ to 4 feet long, 27 to 30 inches wide and 14

inches deep, resting on legs of different lengths, so that the mixtures will readily flow to the lower corner of the box, which should be from 8 to 10 inches above the pavement. This mixture, from the moment it touches the brick, shall be thoroughly swept into the joints.

Two such boxes shall be provided in case the street is twenty feet or less in width; exceeding twenty feet in width, three boxes should be used.

The work of filling should thus be carried forward in line until an advance of fifteen to twenty yards has been made, when the same force and appliances shall be turned back and cover the same space in like manner, except to make the proportions two-thirds Portland cement and one-third sand.

To avoid the possibility of the thickening at any point, there should be a man with a sprinkling can, the head perforated with small holes, sprinkling gently the surface ahead of the sweepers.

Within one-half to three-quarters of an hour after this last coat is applied and the grout between the joints has fully subsided and the initial set is taking place, the whole surface must be slightly sprinkled and all surplus mixture left on the tops of the bricks swept into the joints, bringing them up flush and full.

After the joints are thus filled flush with the top of the bricks and sufficient time for evaporation has taken place, so that the coating of sand will not absorb any moisture from the cement mixture, one-half inch of sand shall be spread over the whole surface, and in case the work is subjected to a hot summer sun, an occasional sprinkling, sufficient to dampen the sand, should be followed for two or three days.

EXTRA MENTION.—Dry, sharp sand for this mixture is necessary without question or comment.

The first application should be thin in order that it may flow to the depth of the joints of the bricks, thereby insuring a substantial bond, and should be kept in constant motion while being applied, otherwise the sand will settle and you will have water and cement instead of water, sand and cement. The water and cement wouldn't be objectionable, but the sand by itself is wholly so.

It must also be mixed in small quantities, as it is next to impossible to keep the sand in suspension when more than a common water pail of each, sand and cement, is used, and unless it is deposited upon the pavement with the sand in combination with the solution you will get the cement and water in the lower portion of the joints between the bricks and the sand without the cement in the upper portion. It is preferable, after the sand and cement have been mixed dry, to apply sufficient water and mix slowly, first to a good mortar, then add sufficient water to bring the mortar to the required consistency. By this method a more thorough adhesion of the cement to the sand can be obtained. Some one, some day, may perfect a mechanical device for doing this satisfactorily, but at this time no such method is known. The rocking trough has been tried for the mixing and discharging, but invariably the cement will flow out first, then follows the sand to fill the upper parts of the joints; therefore, the safest way is to use the scoop shovel as the specifications direct.

Ten days is the minimum time for keeping the street blockaded and free from traffic. Thirty days would be better. and longer if it were possible. In testing laboratories the usual time for allowing cements (neat cements at that) to stand before applying the tests, is twenty-seven days. Therefore, when you open a grouted street to traffic in ten days you are demanding and expecting more from the cement than any

testing laboratory would, so the streets should remain closed as long as a suffering public will permit.

It is urgently insisted that in no case shall the proportion of cement be lessened.

Grouting thus finished must remain absolutely free from disturbance or traffic of any kind for a period of ten days, at least. These specifications, closely and skillfully followed, will give you the three important factors of a desirable city thoroughfare—DURABILITY, COMFORT OF TRAVEL, PERFECT SATISFACTION.

The foregoing are some of the many reasons why the above instructions for brick street building should be embodied in all specifications by the authorities.

One of the greatest difficulties experienced by engineers in securing a compliance with specifications, is the fact that details more often than otherwise are left to foremen unacquainted with directions found in the specifications.

It has been found in the experience of many, that if the contract for the performance of any particular work embody a requirement that all foremen on the work be supplied at all times and that they be familiar with specifications and directions covering the portions of the work with which they are charged, a strict compliance with all the details is more easily secured.